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Zhou

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(54) **CHIP-ON-CHIP POWER CARD WITH EMBEDDED DIRECT LIQUID COOLING**

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(51) **Int. Cl.**

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H01L 23/34	(2006.01)
H01L 21/00	(2006.01)
H05K 7/18	(2006.01)
H01L 23/473	(2006.01)
H01L 21/48	(2006.01)
H01L 25/00	(2006.01)
H01L 25/07	(2006.01)
H05K 7/20	(2006.01)
H01L 23/00	(2006.01)
H01L 33/62	(2010.01)

(52) **U.S. Cl.**

CPC ***H01L 23/473*** (2013.01); ***H01L 21/4821*** (2013.01); ***H01L 23/49537*** (2013.01); ***H01L 23/49541*** (2013.01); ***H01L 23/49575*** (2013.01); ***H01L 25/072*** (2013.01); ***H01L 25/50*** (2013.01); ***H05K 7/20872*** (2013.01); *H01L 24/32* (2013.01); *H01L 24/33* (2013.01); *H01L 33/62* (2013.01); *H01L 2224/32245* (2013.01); *H01L 2224/33181* (2013.01)

(58) **Field of Classification Search**

CPC ... H01L 21/4821; H01L 33/62; H01L 25/072; H01L 25/50; H01L 23/473; H01L 23/49537; H01L 23/49541; H01L 23/49575; H01L 23/49513; H01L 23/49568

See application file for complete search history.

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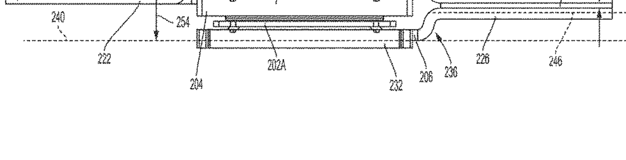
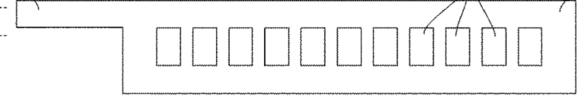
Primary Examiner — Alonzo Chambliss
(74) *Attorney, Agent, or Firm* — Snell & Wilmer LLP

(57) **ABSTRACT**

Methods, systems, and apparatuses for a power card for use in a vehicle. The power card includes an N lead frame, a P lead frame, and an O lead frame each having a body portion and a terminal portion, with the O lead frame located between the N lead frame and the P lead frame. The power card includes a first power device being located on a first side of the O lead frame and a second power device being located on a second side of the O lead frame, the body portion of the O lead frame having one or more channels configured to receive a cooling liquid for cooling the first power device and the second power device.

20 Claims, 28 Drawing Sheets





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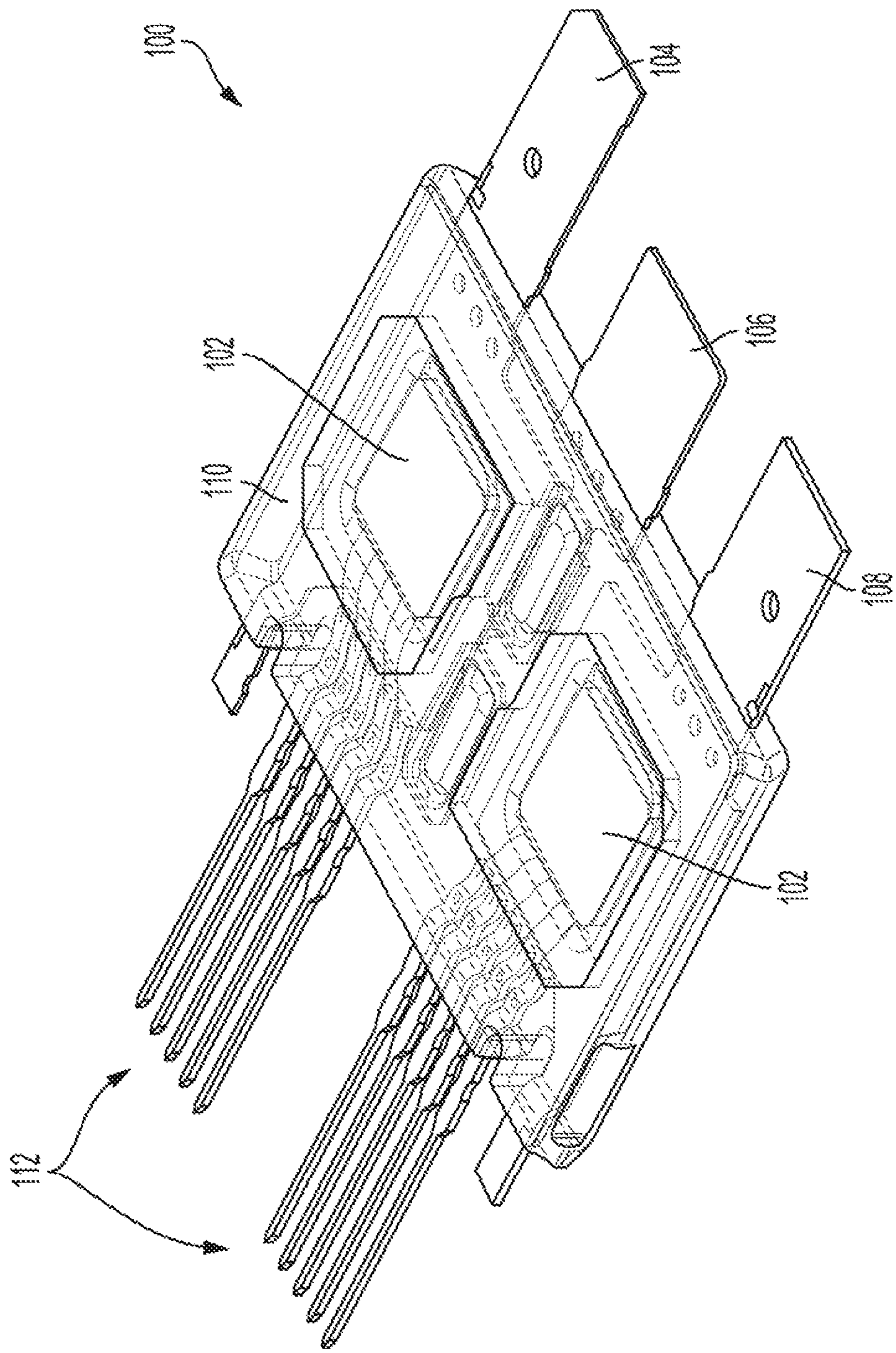

FIG. 1A

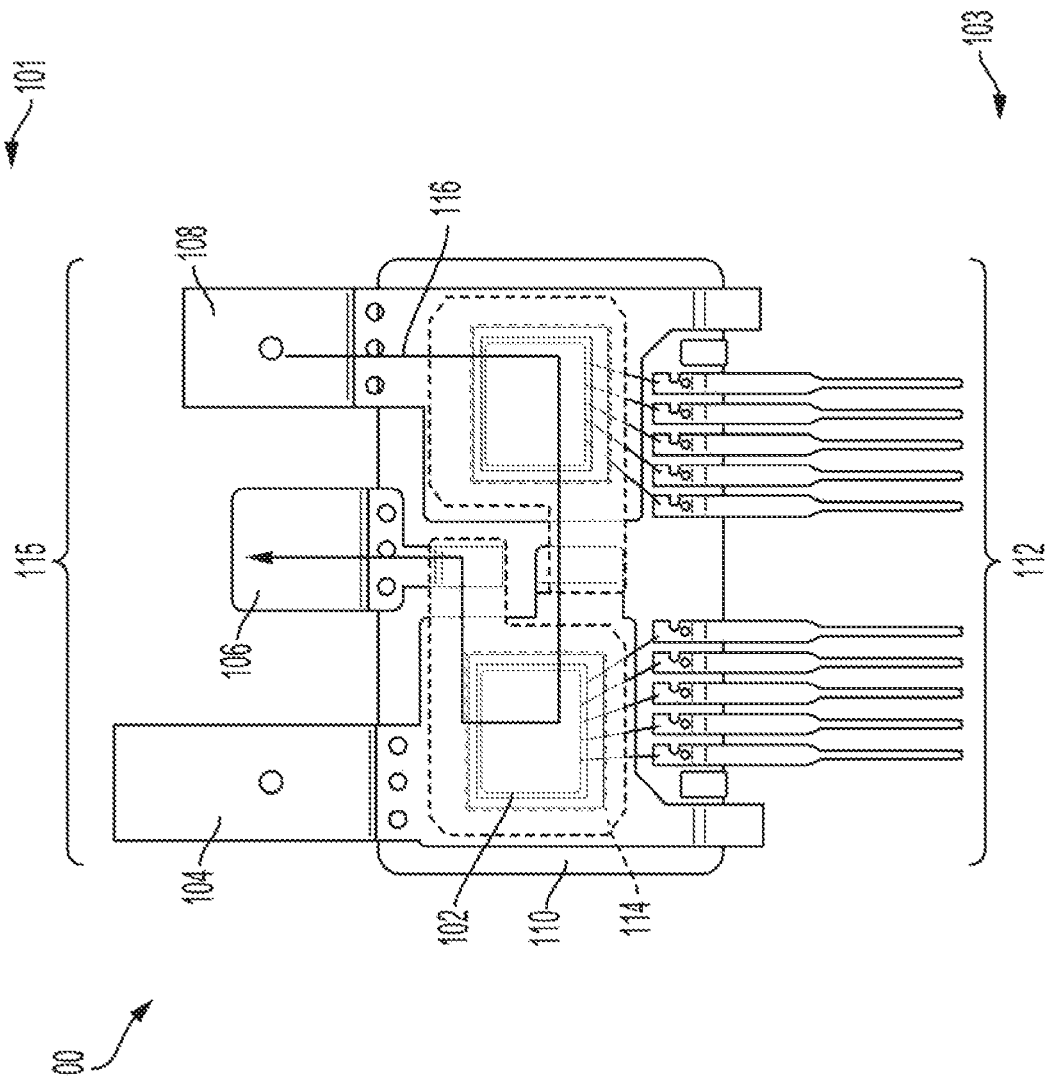

FIG. 1B

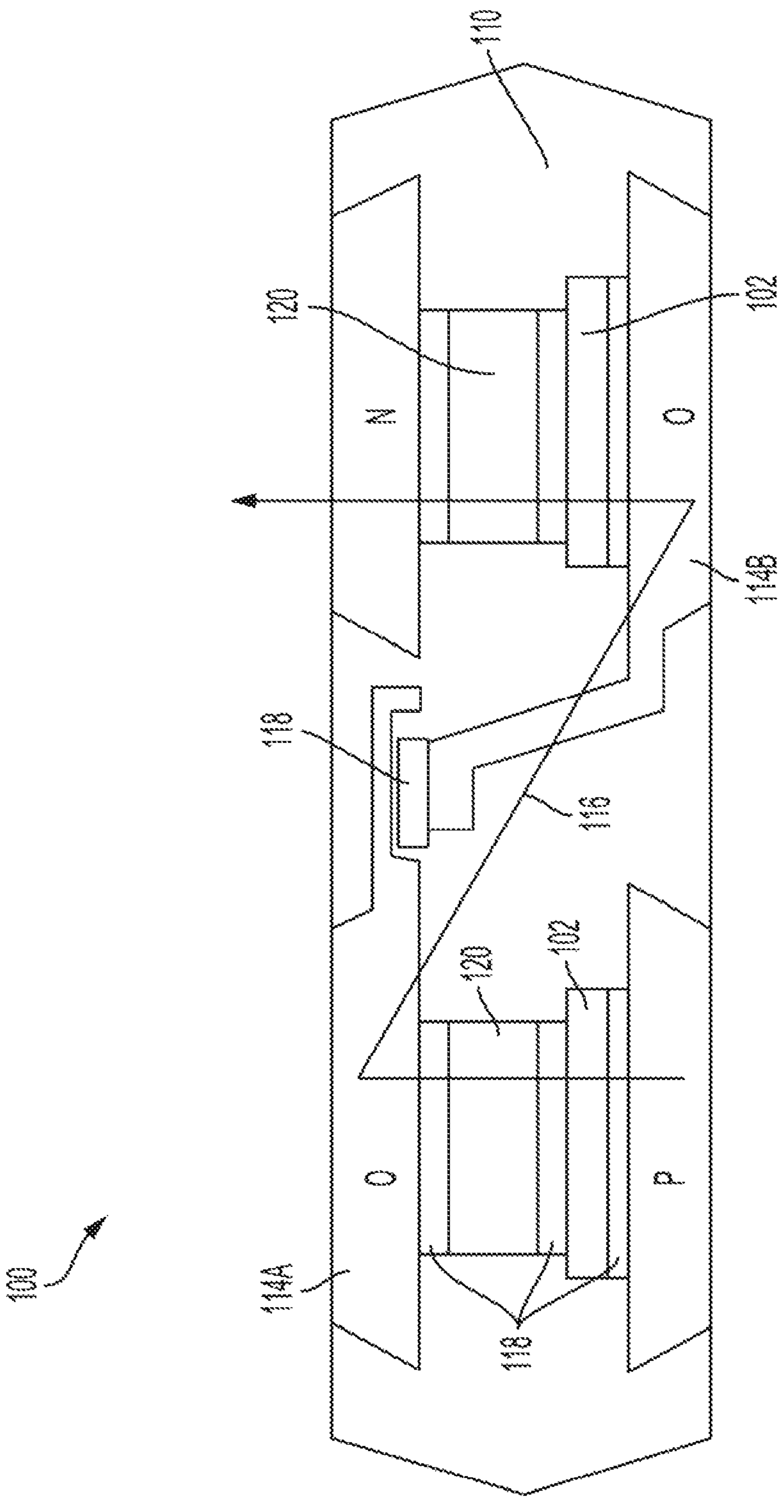

FIG. 1C

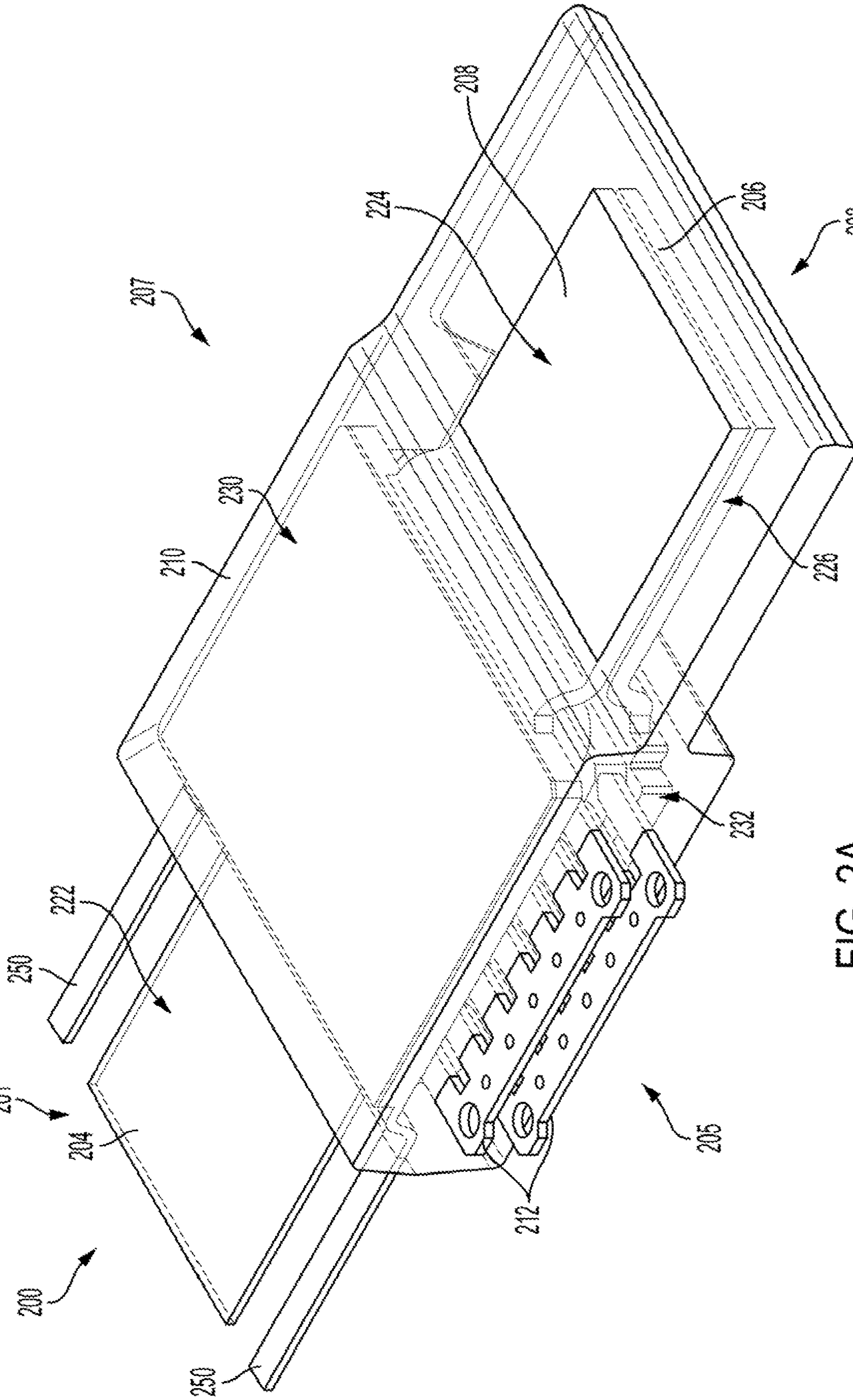
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FIG. 2A

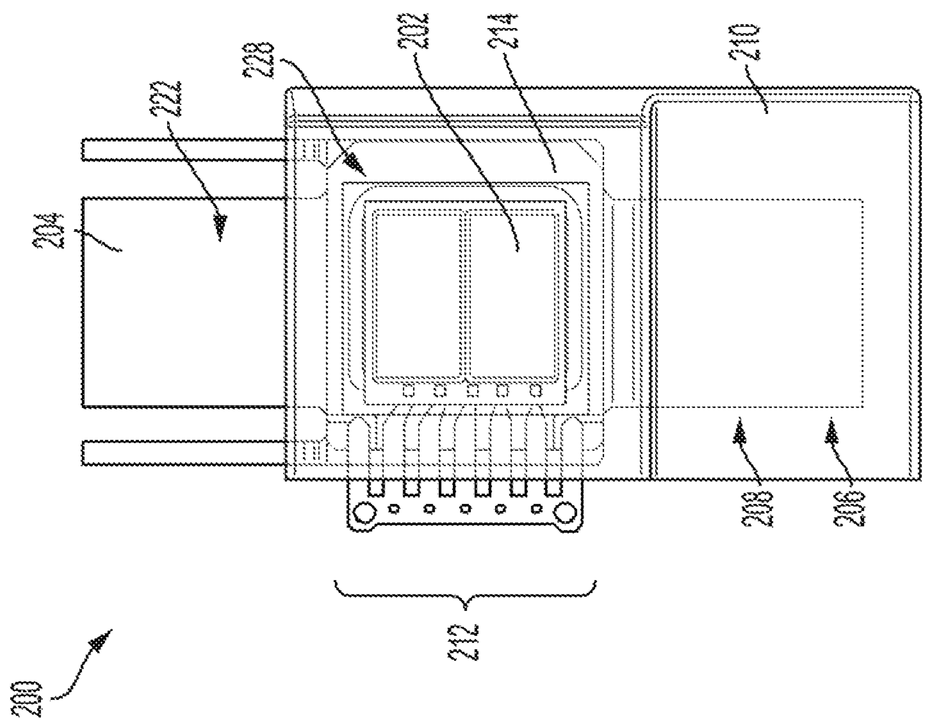

FIG. 2B

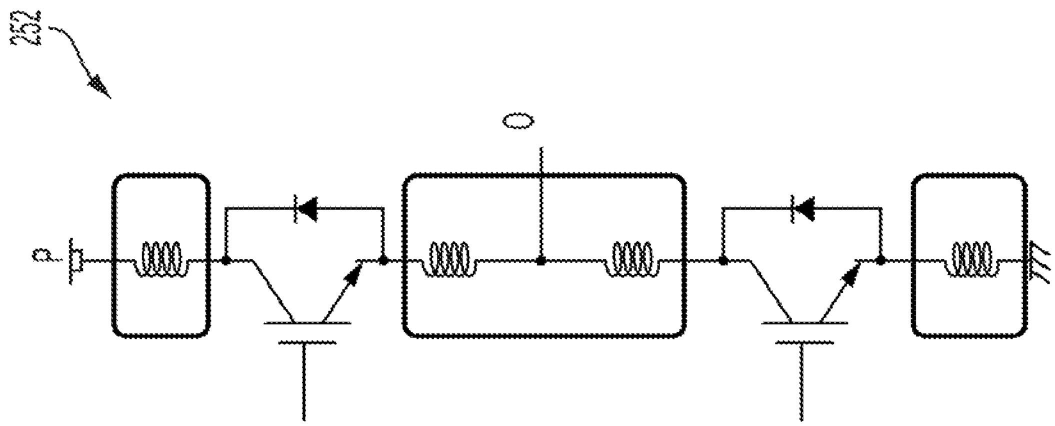
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FIG. 2D

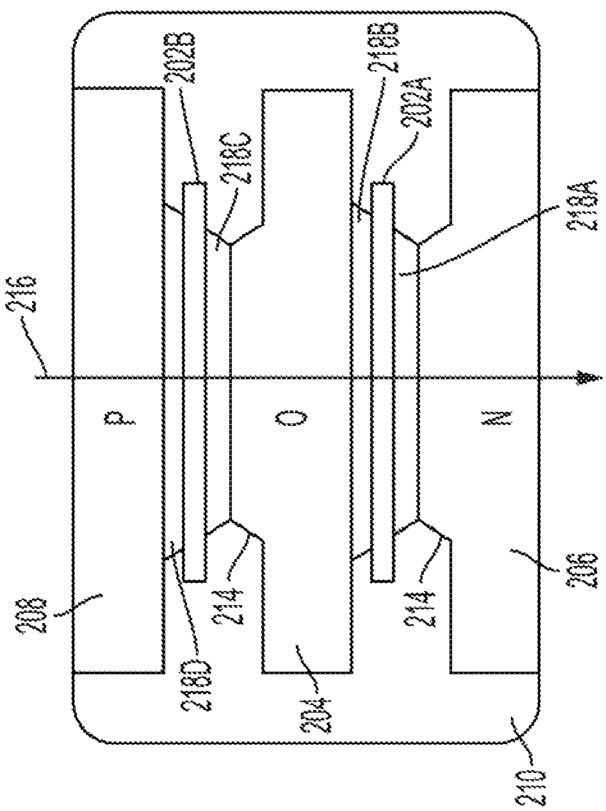
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FIG. 2C

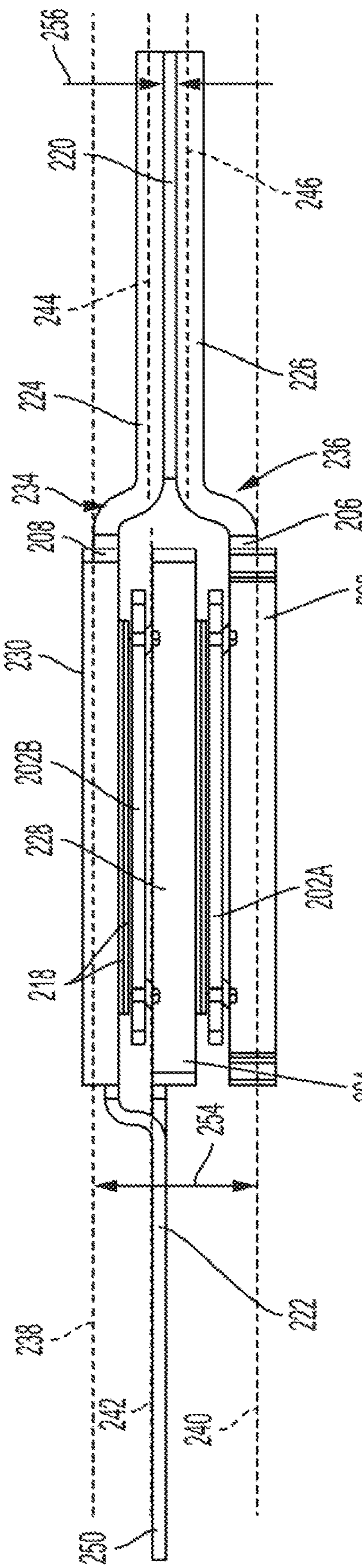
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FIG. 2E

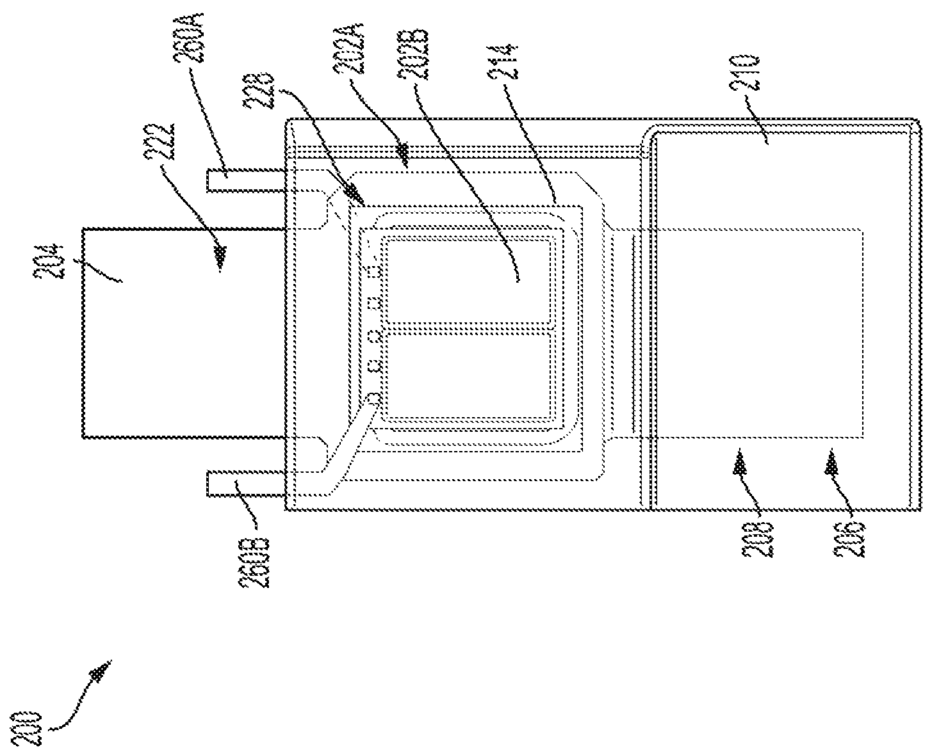


FIG. 2F

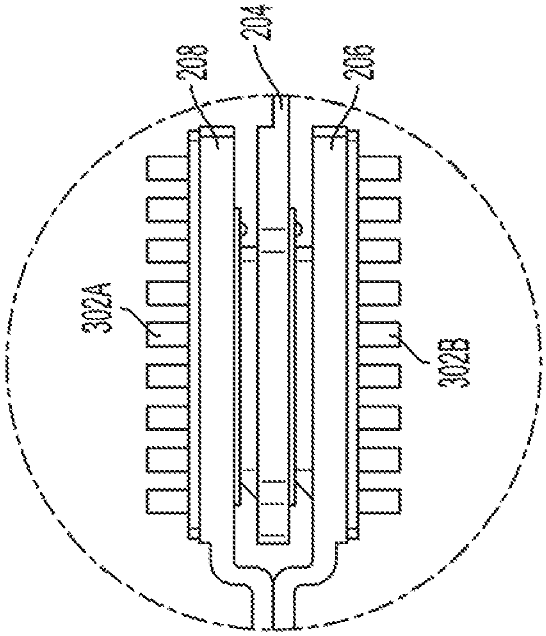


FIG. 3B

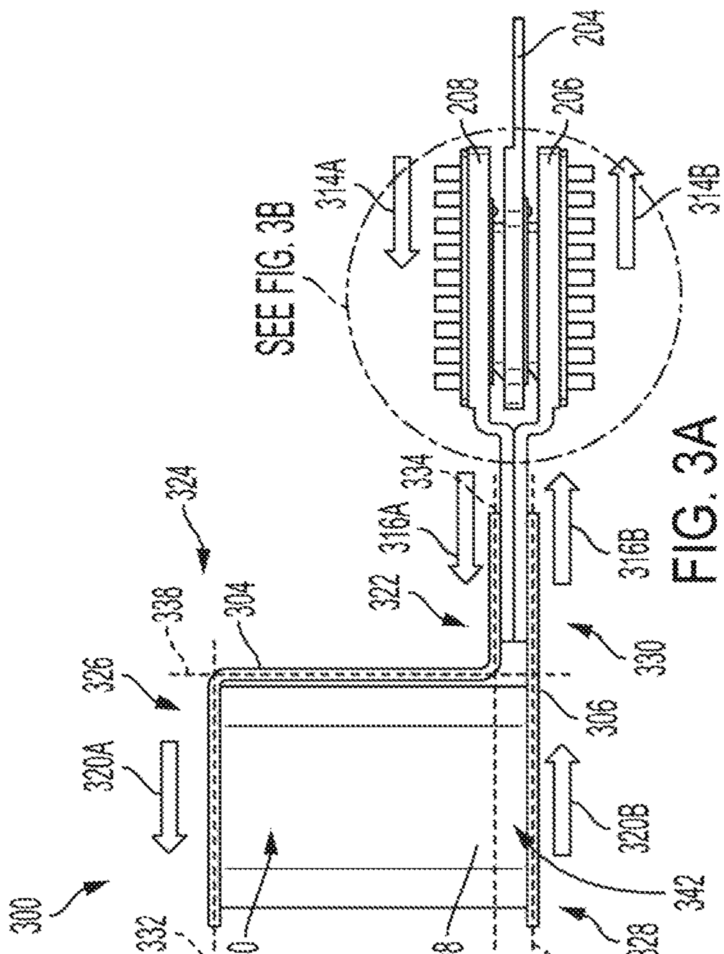


FIG. 3A

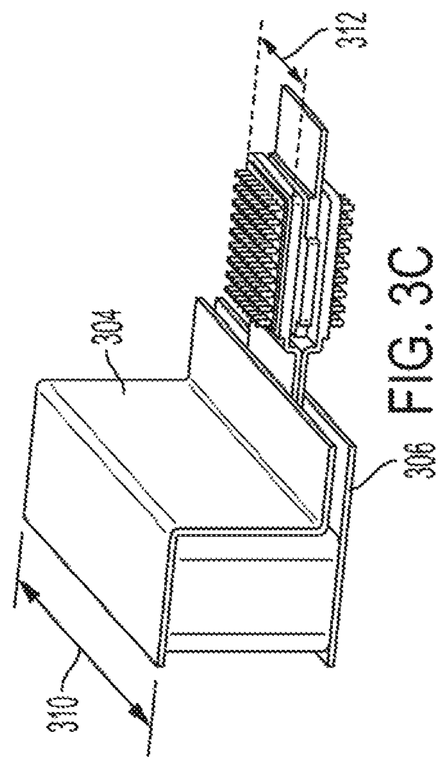
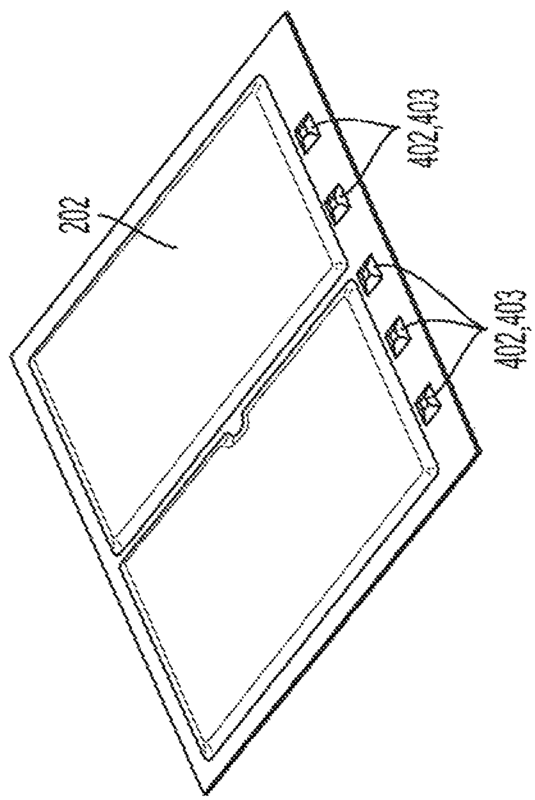


FIG. 3C



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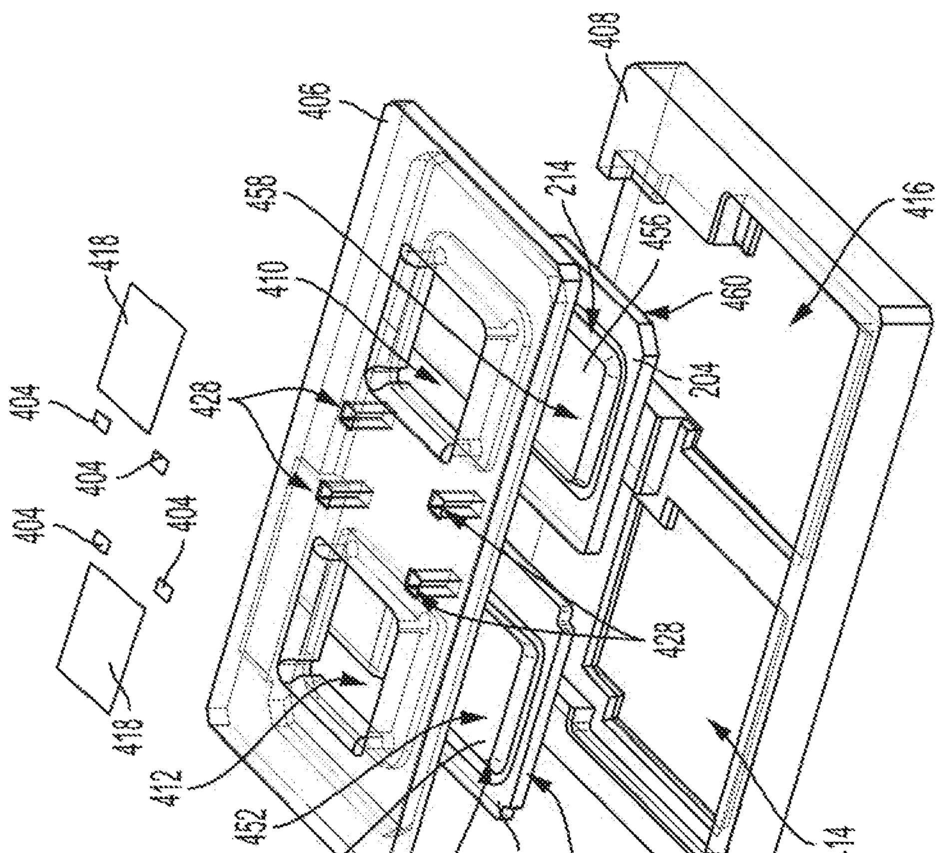

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FIG. 4B

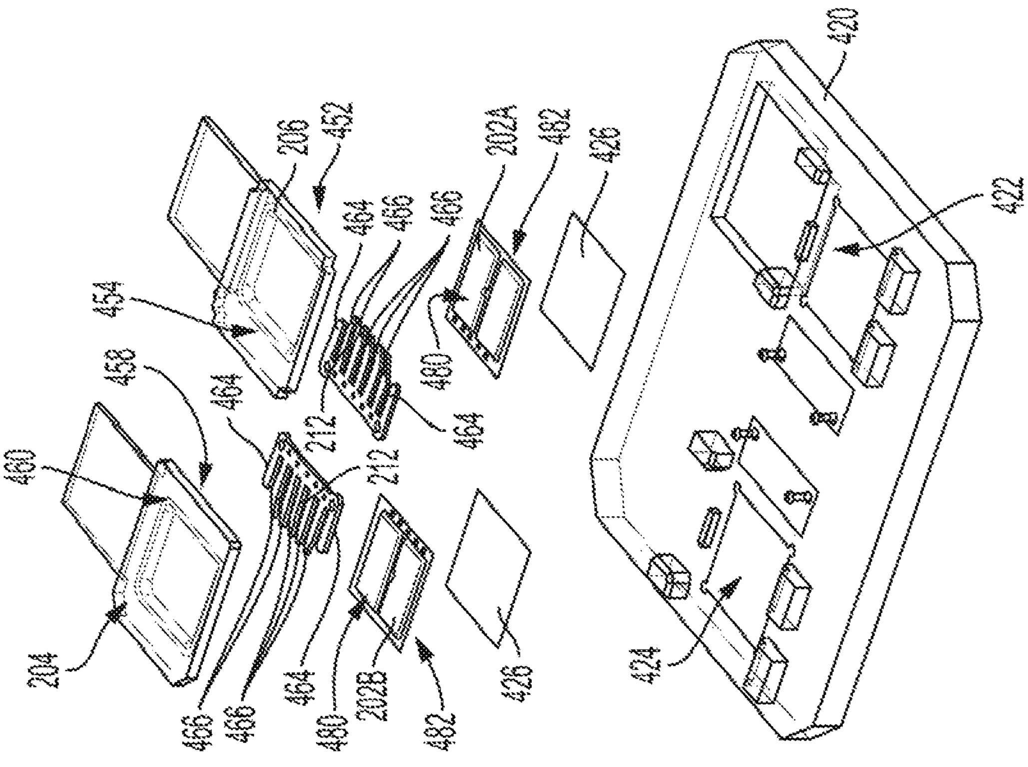
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FIG. 4C

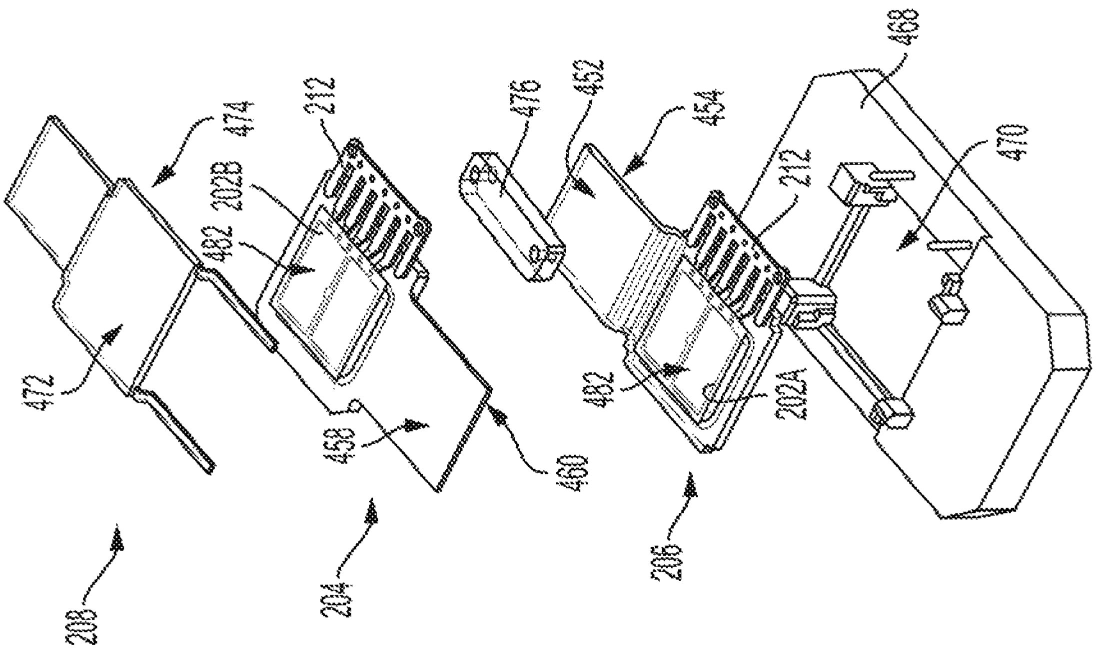
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FIG. 4D

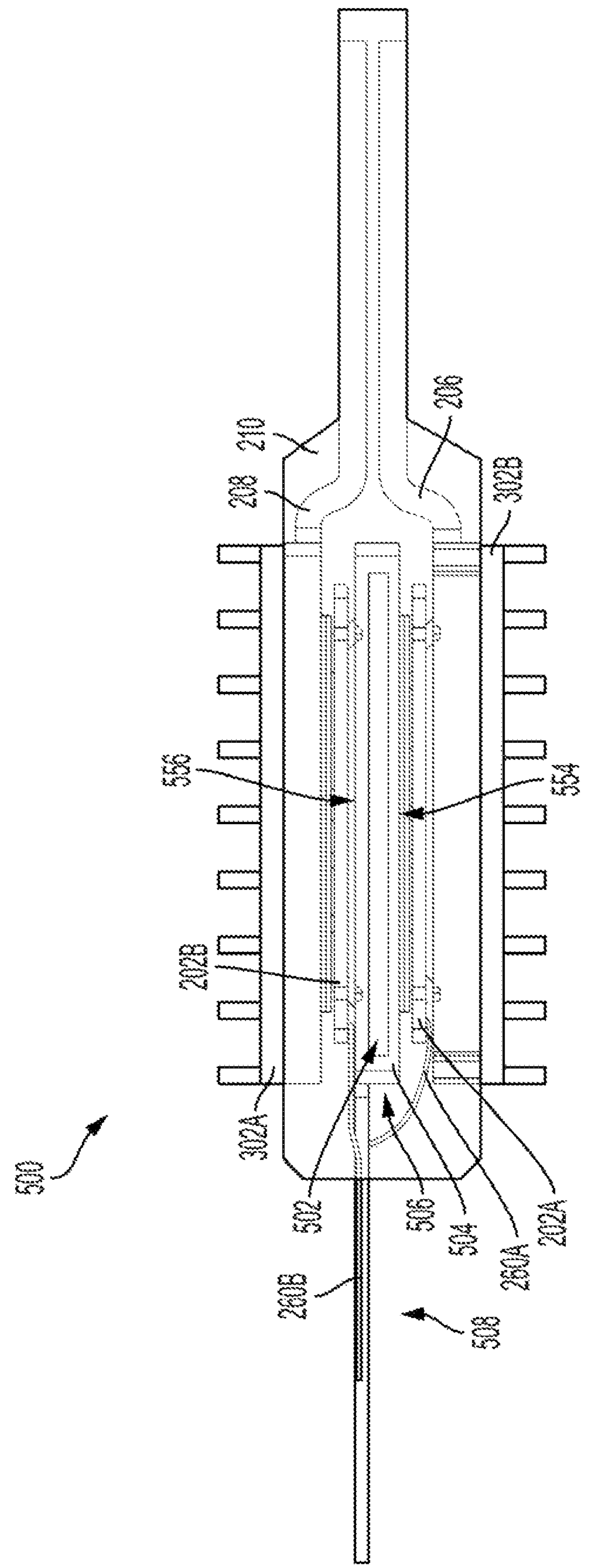
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FIG. 5A

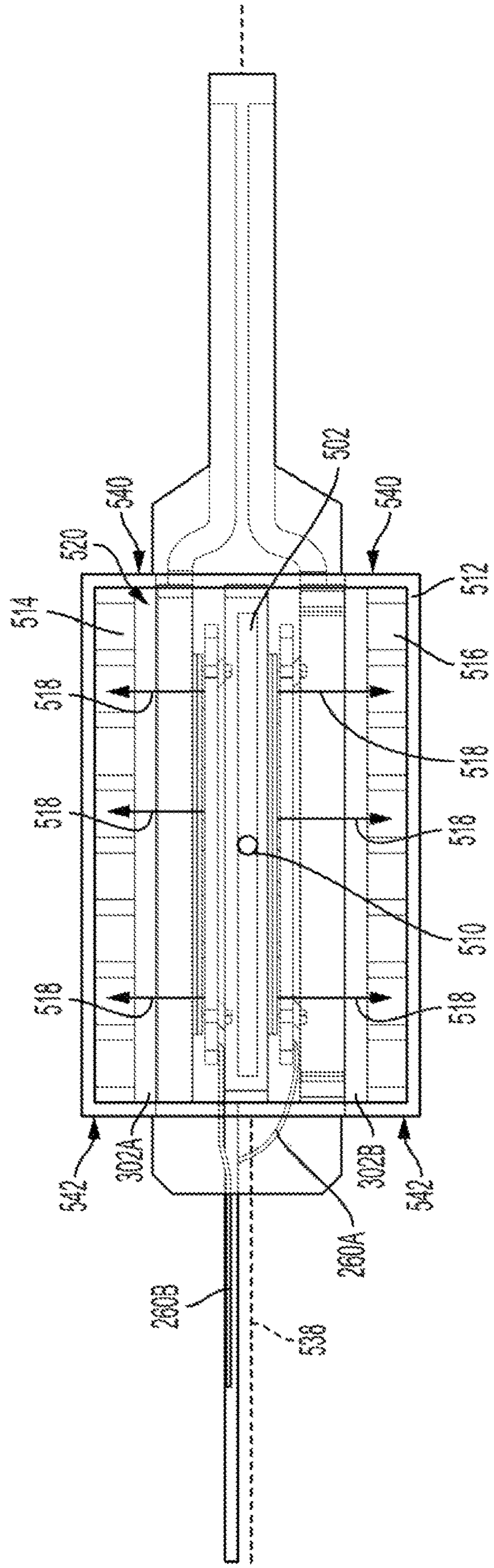
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FIG. 5B

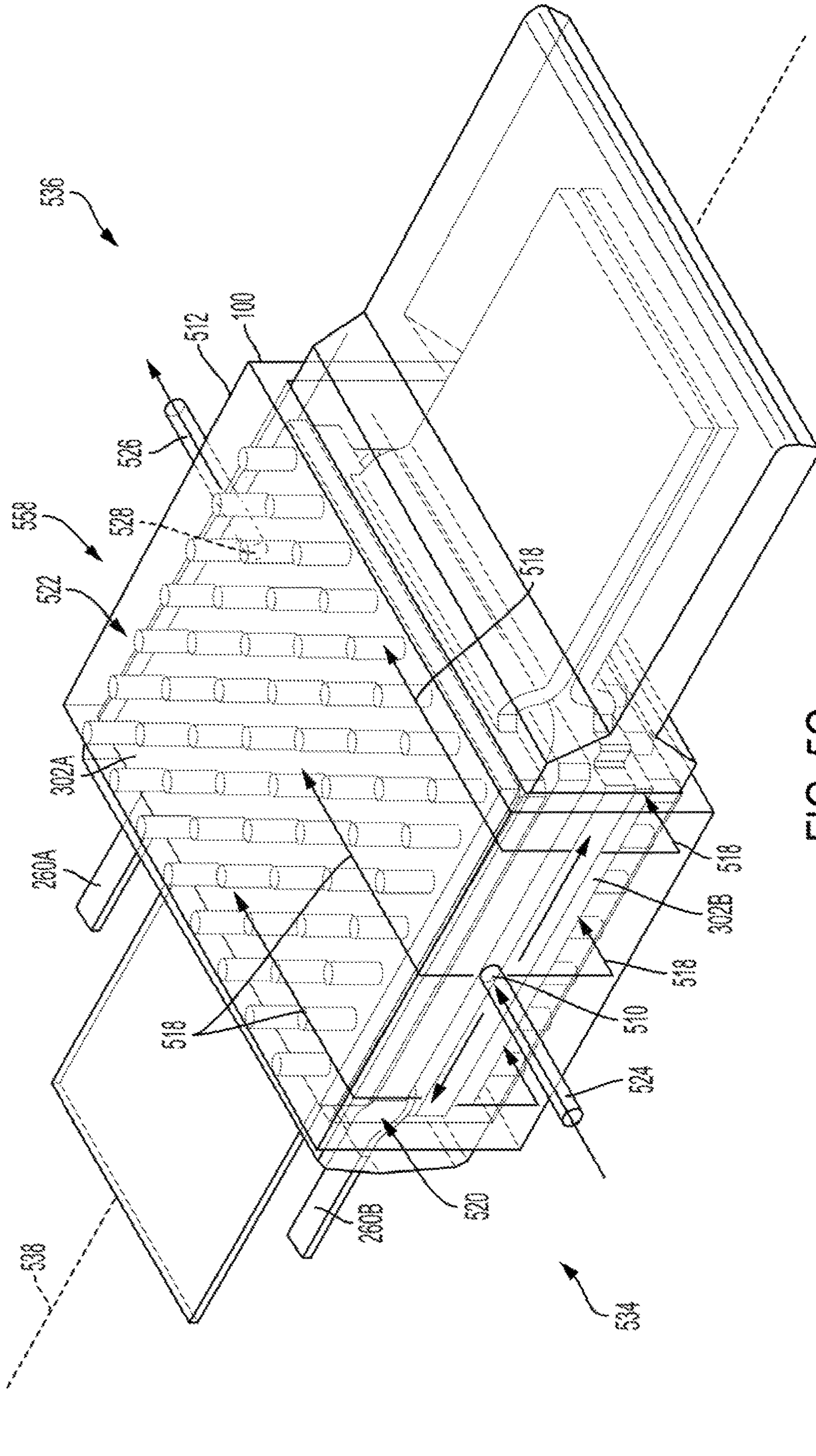
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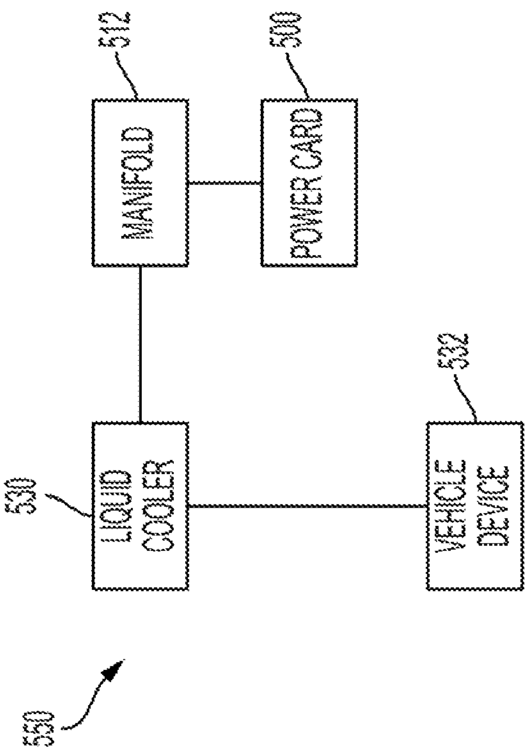
FIG. 5C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MANIFOLD
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POWER CARD
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LIQUID COOLER
532
VEHICLE DEVICE
550

FIG. 5D

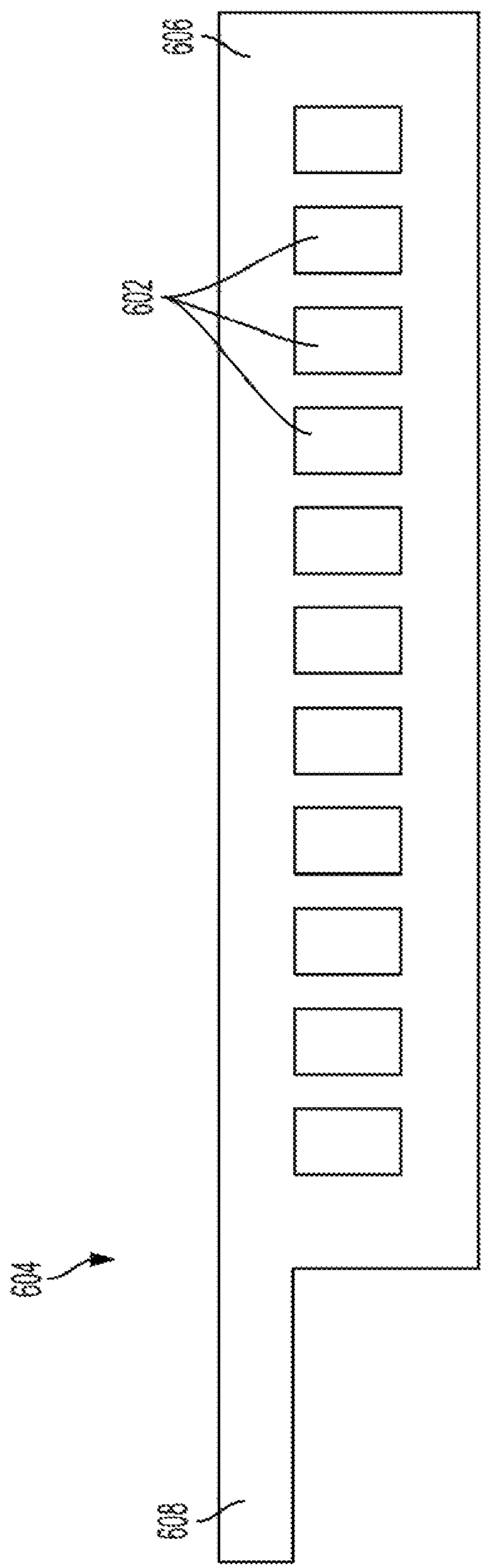

FIG. 6

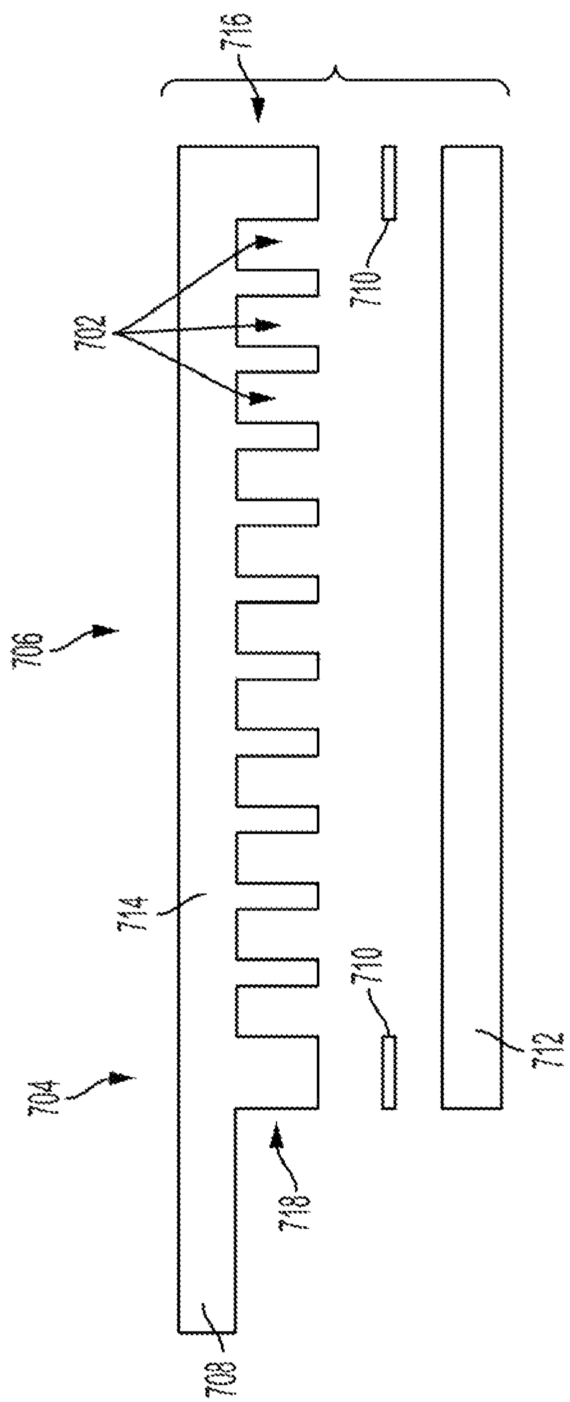

FIG. 7

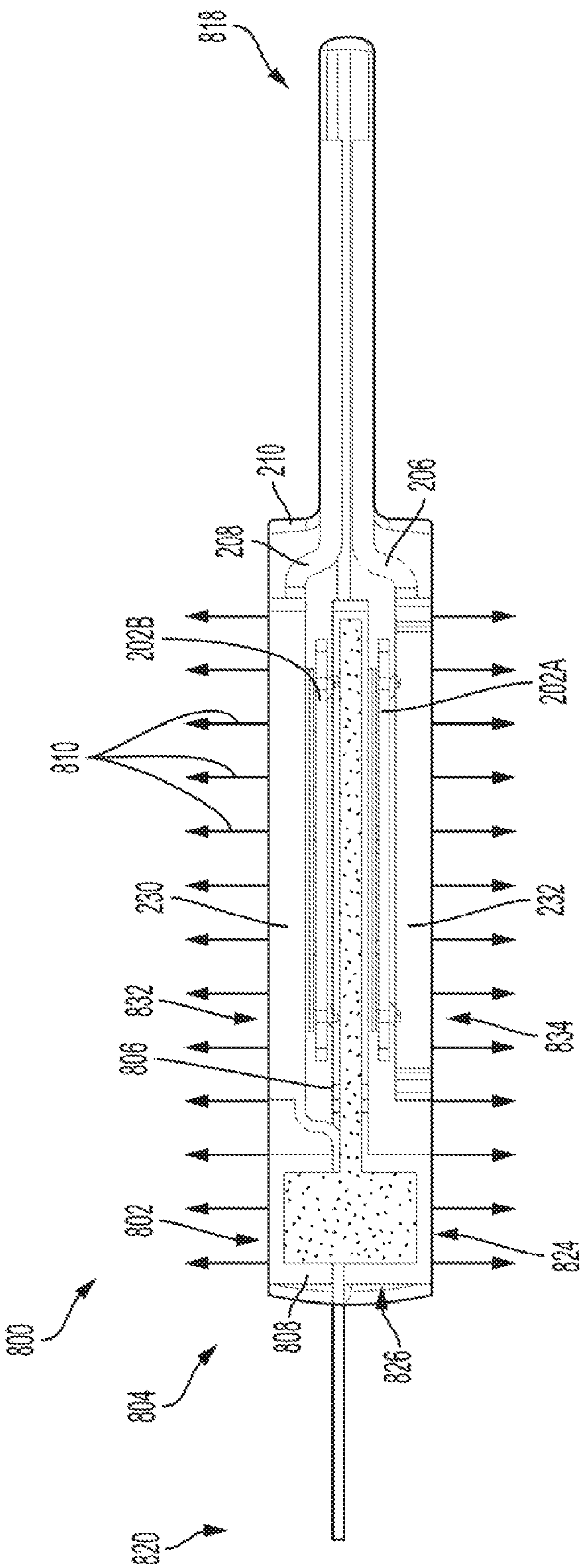
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FIG. 8

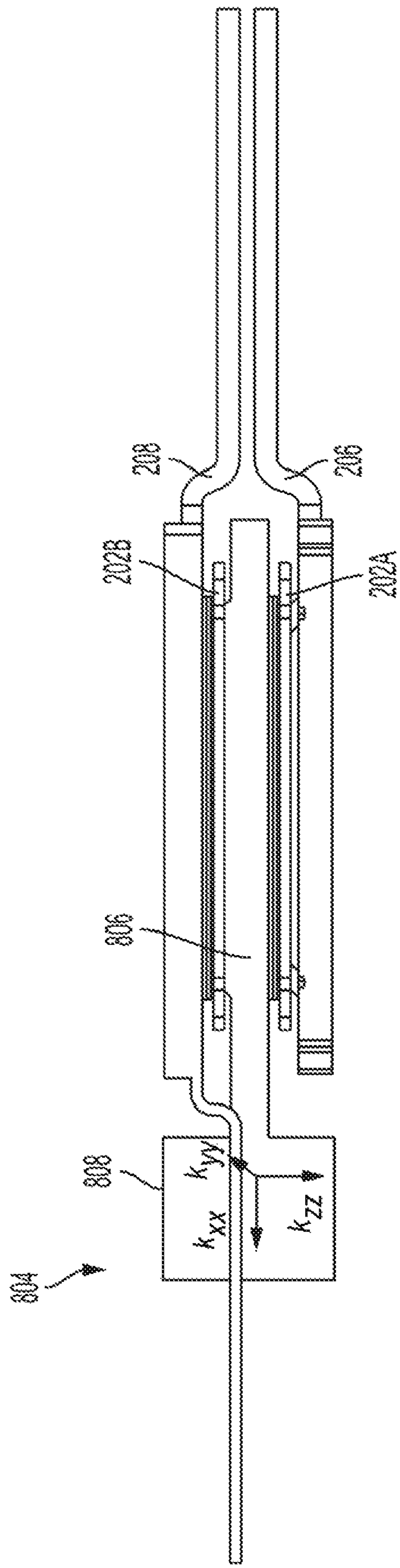

FIG. 9

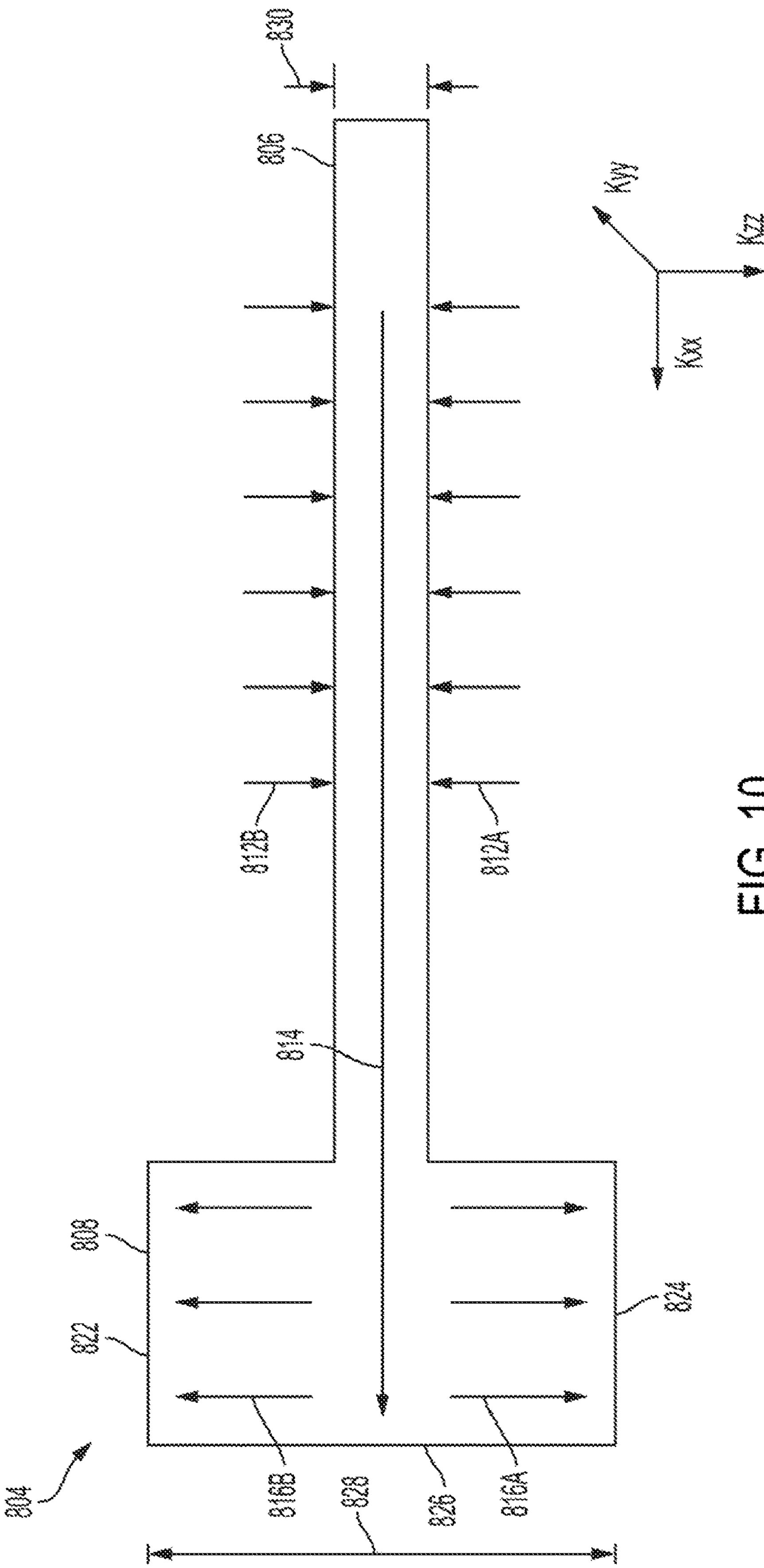
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FIG. 10

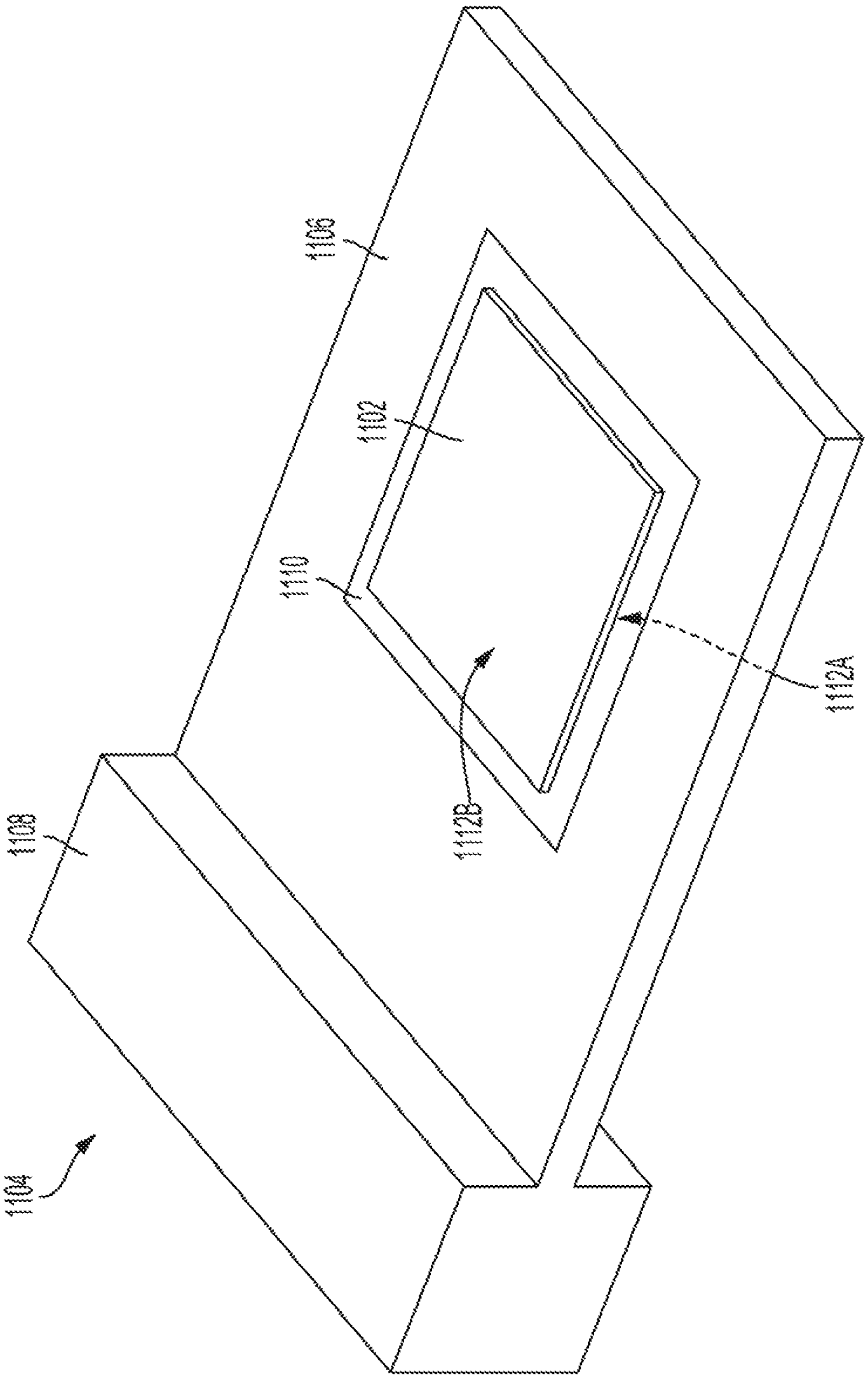

FIG. 11

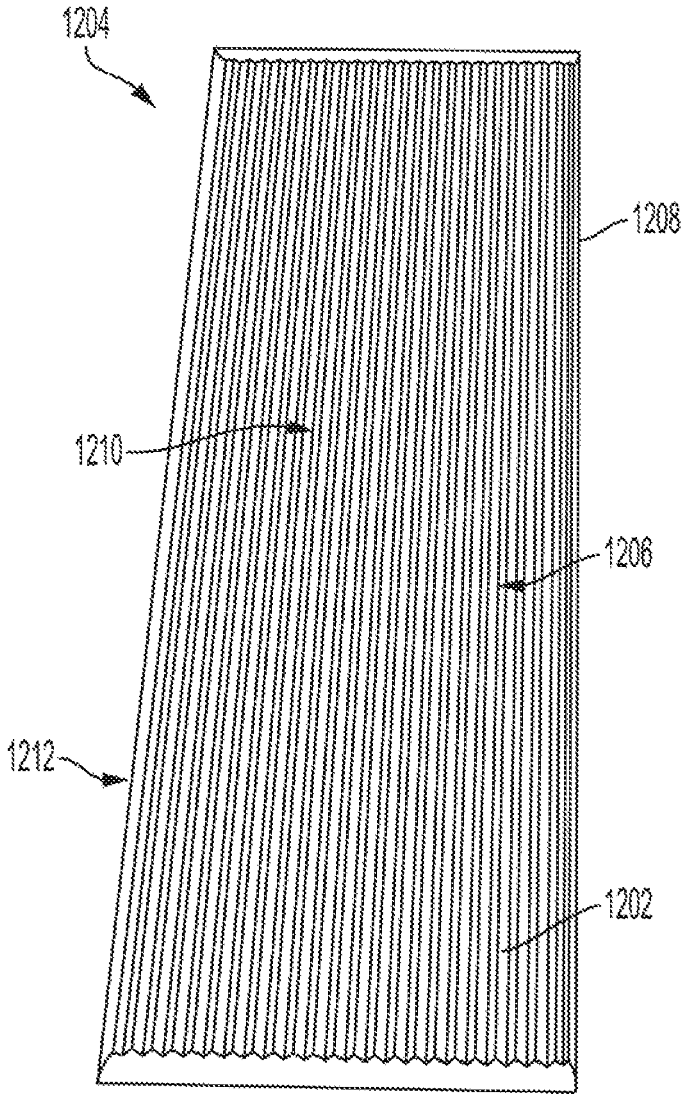

FIG. 12

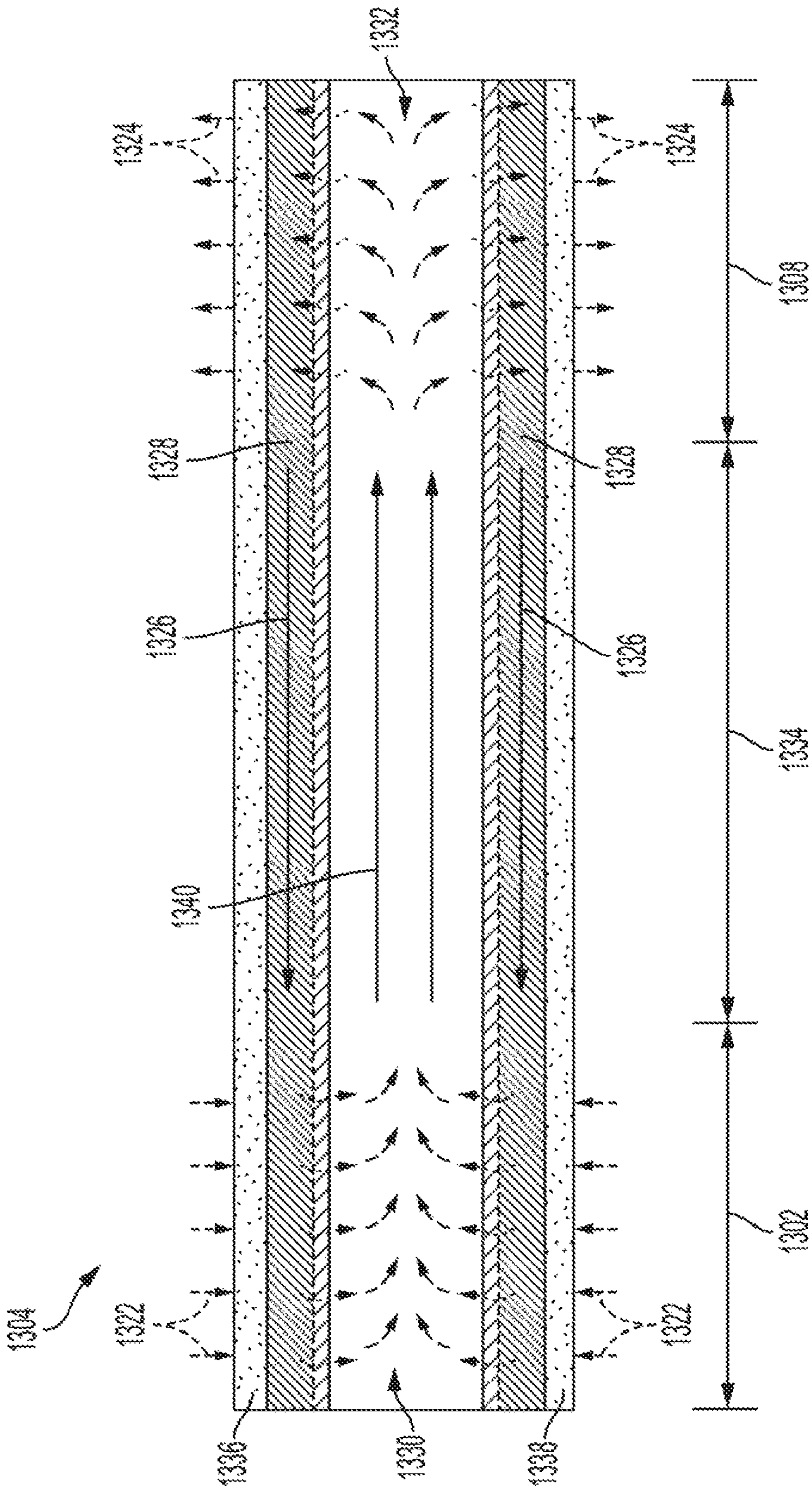
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FIG. 13

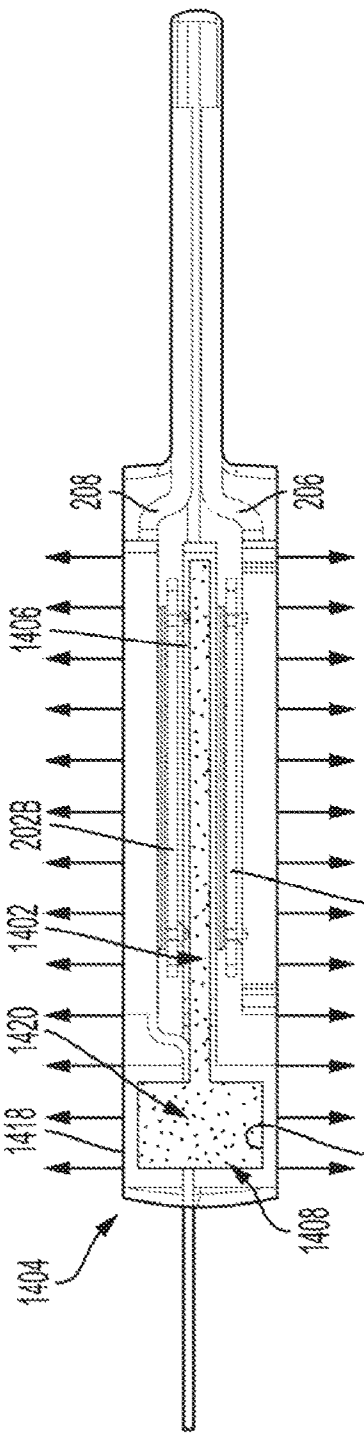


FIG. 14A

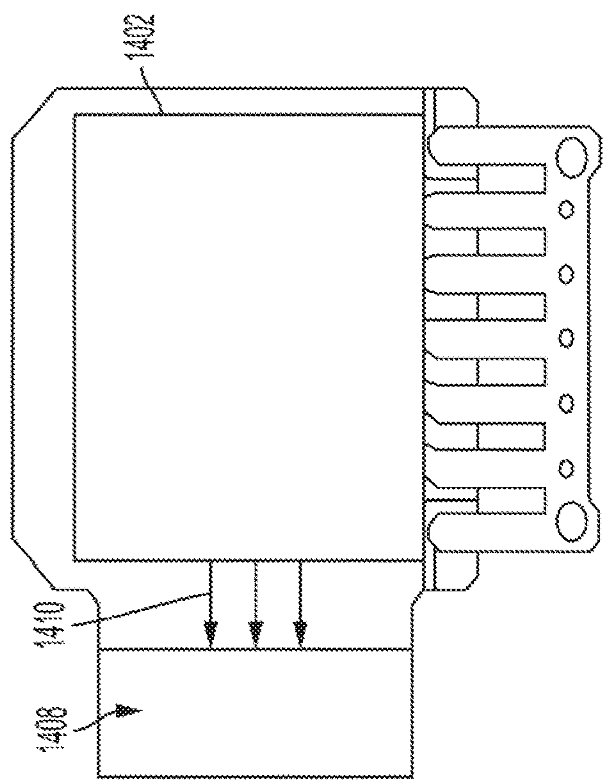


FIG. 14B

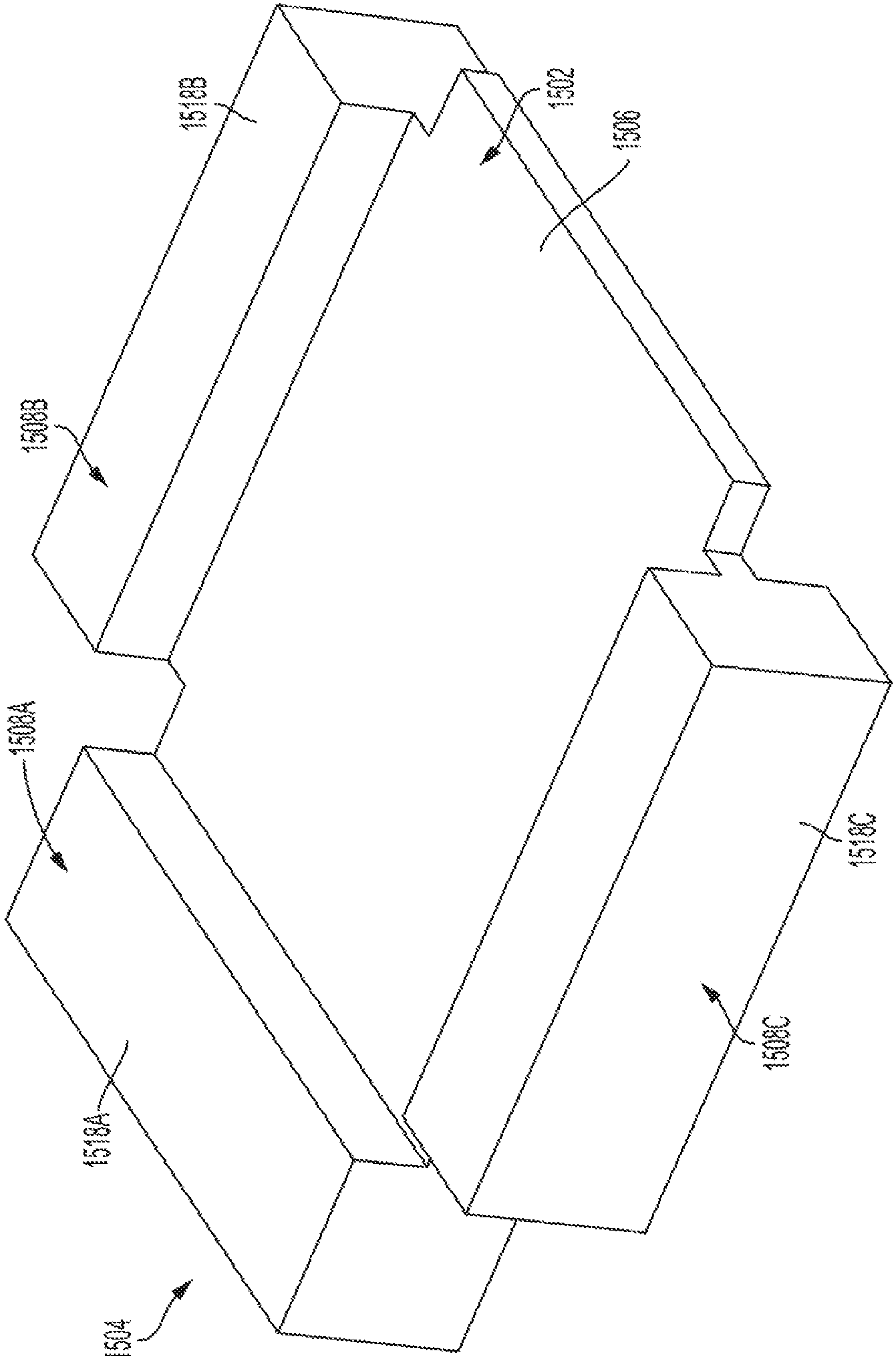
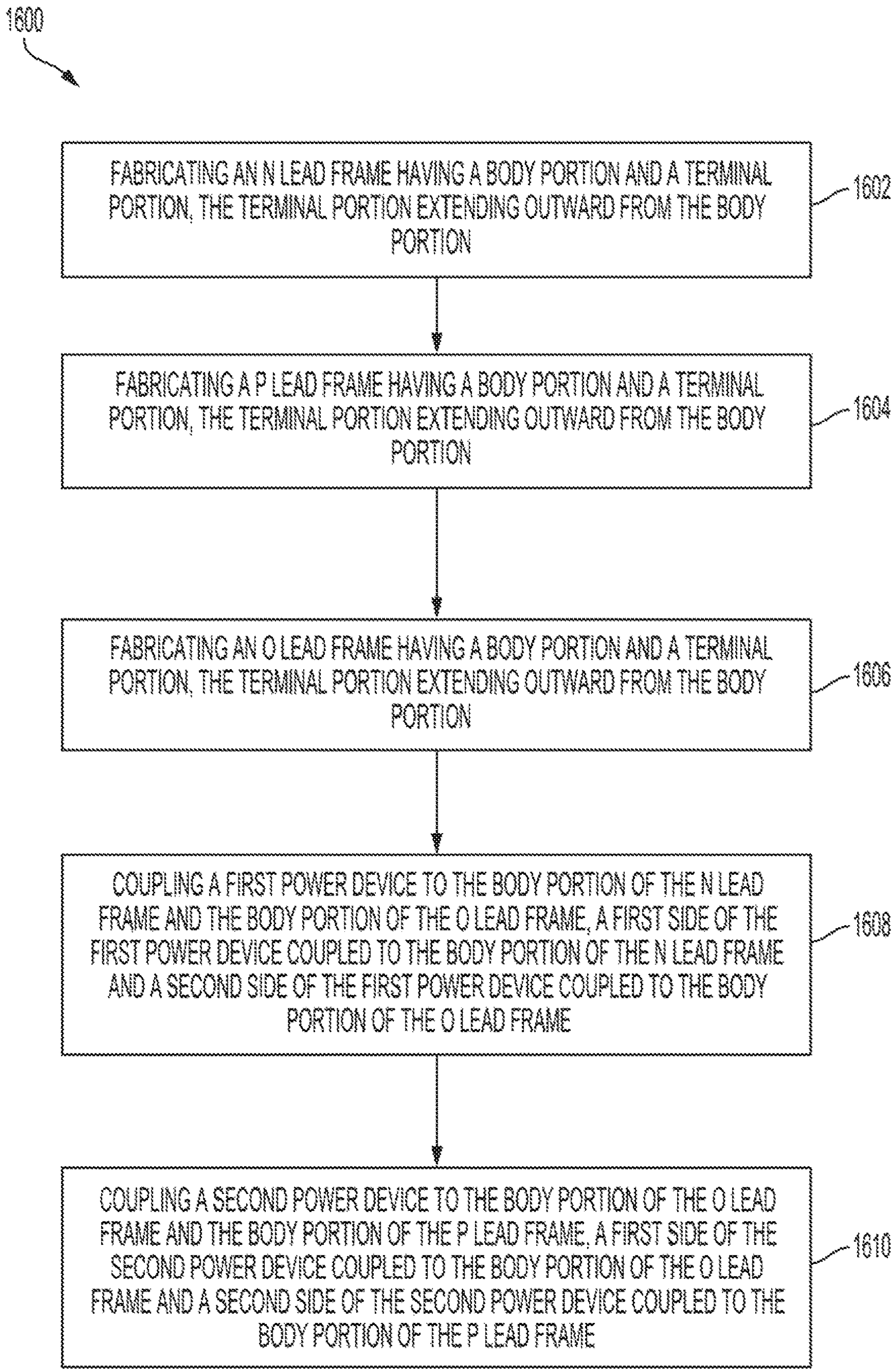


FIG. 15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FABRICATING AN N LEAD FRAME HAVING A BODY PORTION AND A TERMINAL PORTION, THE TERMINAL PORTION EXTENDING OUTWARD FROM THE BODY PORTION
1602
FABRICATING A P LEAD FRAME HAVING A BODY PORTION AND A TERMINAL PORTION, THE TERMINAL PORTION EXTENDING OUTWARD FROM THE BODY PORTION
1604
FABRICATING AN O LEAD FRAME HAVING A BODY PORTION AND A TERMINAL PORTION, THE TERMINAL PORTION EXTENDING OUTWARD FROM THE BODY PORTION
1606
COUPLING A FIRST POWER DEVICE TO THE BODY PORTION OF THE N LEAD FRAME AND THE BODY PORTION OF THE O LEAD FRAME, A FIRST SIDE OF THE FIRST POWER DEVICE COUPLED TO THE BODY PORTION OF THE N LEAD FRAME AND A SECOND SIDE OF THE FIRST POWER DEVICE COUPLED TO THE BODY PORTION OF THE O LEAD FRAME
1608
COUPLING A SECOND POWER DEVICE TO THE BODY PORTION OF THE O LEAD FRAME AND THE BODY PORTION OF THE P LEAD FRAME, A FIRST SIDE OF THE SECOND POWER DEVICE COUPLED TO THE BODY PORTION OF THE O LEAD FRAME AND A SECOND SIDE OF THE SECOND POWER DEVICE COUPLED TO THE BODY PORTION OF THE P LEAD FRAME
1610

FIG. 16

CHIP-ON-CHIP POWER CARD WITH EMBEDDED DIRECT LIQUID COOLING

BACKGROUND

1. Field

This specification relates to a compact low inductance chip-on-chip power card and method of manufacturing the same.

2. Description of the Related Art

Modern vehicles use electricity as part of the operation of the vehicle. These vehicles may be operated using electricity exclusively, or by using a combination of electricity and another energy source. Many modern vehicles include a power control unit (PCU) configured to manage the energy amongst multiple different vehicle electrical systems. In the case of vehicles driven by electric motors, a power control unit may be used to control the electric motor, including torque and speed of the motor. A component of the power control unit is a power card, which contains power devices that may be switched on and off in high frequency during operation of the vehicle. These power devices may generate significant amounts of heat. Conventional power cards have designs for exposing surface area of the power devices for cooling purposes. However, these conventional power cards are bulky and not useful in compact space contexts. Thus, there is a need for a power card capable of providing cooling and being compact.

SUMMARY

What is described is a power card for use in a vehicle. The power card includes an N lead frame having a body portion and a terminal portion, the terminal portion extending outward from the body portion. The power card also includes a P lead frame having a body portion and a terminal portion, the terminal portion extending outward from the body portion. The power card also includes an O lead frame having a body portion and a terminal portion, the terminal portion extending outward from the body portion, the O lead frame being located between the N lead frame and the P lead frame. The power card also includes a first power device being located on a first side of the O lead frame between the body portion of the N lead frame and the body portion of the O lead frame. The power card also includes a second power device being located on a second side of the O lead frame between the body portion of the O lead frame and the body portion of the P lead frame, the body portion of the O lead frame having one or more channels configured to receive a cooling liquid for cooling the first power device and the second power device.

Also described is a power system having a power card and a liquid cooler. The power card includes an O lead frame located between an N lead frame and a P lead frame. The power card also includes a first power device located on a first side of the O lead frame between the N lead frame and the O lead frame. The power card also includes a second power device located on a second side of the O lead frame between the O lead frame and the P lead frame, the O lead frame having one or more channels configured to receive a cooling liquid for cooling the first power device and the second power device. The liquid cooler is coupled to the one or more channels of the O lead frame and configured to provide the cooling liquid to the one or more channels of the O lead frame.

Also described is a lead frame for use in a vehicle power card. The lead frame includes a body portion having a first side coupled to a first power device, a second side coupled to a second power device, and one or more channels configured to receive a cooling liquid for cooling the first power device and the second power device. The lead frame also includes a terminal portion extending outward from the body portion.

BRIEF DESCRIPTION OF THE DRAWINGS

Other systems, methods, features, and advantages of the present invention will be apparent to one skilled in the art upon examination of the following figures and detailed description. Component parts shown in the drawings are not necessarily to scale, and may be exaggerated to better illustrate the important features of the present invention.

FIGS. **1**A-**1**C illustrate a power card, according to various embodiments of the invention.

FIGS. **2**A-**2**F illustrate a compact low inductance chip-on-chip power card, according to various embodiments of the invention.

FIGS. **3**A-**3**C illustrate the compact low inductance chip-on-chip power card connected with a capacitor, according to various embodiments of the invention.

FIGS. **4**A-**4**D illustrate a method of manufacturing the compact low inductance chip-on-chip power card, according to various embodiments of the invention.

FIGS. **5**A-**5**C illustrate a compact low inductance chip-on-chip power card with an O lead frame with integrated channels, according to various embodiments of the invention.

FIG. **5**D illustrates a system using the compact low inductance chip-on-chip power card with an O lead frame with integrated channels, according to various embodiments of the invention.

FIG. **6** illustrates an O lead frame with integrated channels, according to various embodiments of the invention.

FIG. **7** illustrates an exploded O lead frame with integrated channels, according to various embodiments of the invention.

FIG. **8** illustrates a compact low inductance chip-on-chip power card with a thermally conductive O lead frame, according to various embodiments of the invention.

FIG. **9** illustrates a compact low inductance chip-on-chip power card with a graphite O lead frame, according to various embodiments of the invention.

FIG. **10** illustrates a graphite O lead frame, according to various embodiments of the invention.

FIG. **11** illustrates a graphite and copper O lead frame, according to various embodiments of the invention.

FIG. **12** illustrates a heat pipe, according to various embodiments of the invention.

FIG. **13** illustrates a cross-sectional view of a vapor chamber, according to various embodiments of the invention.

FIG. **14**A-**14**B illustrate views of a vapor chamber O lead frame, according to various embodiments of the invention.

FIG. **15** illustrates an O lead frame with three cooling surfaces, according to various embodiments of the invention.

FIG. **16** illustrates a flowchart of a process of fabricating the system, according to various embodiments of the invention.

DETAILED DESCRIPTION

Disclosed herein are power cards and methods of manufacture thereof. A power card may be a part of a power control unit of a vehicle. The power control unit is configured to manage the energy amongst multiple different vehicle electrical systems. In vehicles with electric motors, the power control unit may be responsible for operation of the electric motor. The power control unit may include a power card having power devices that are switched on and off at high frequencies during operations of the vehicle. These power devices may be any switch, such as an RC-IGBT, an IGBT/diode combination, or a MOSFET, for example.

Conventional silicon-based power cards have an inductance higher than 20 nH. If silicon carbide is applied, instead of silicon, to the same power card structure, being switched at a higher frequency, high switching losses will be generated due to the relatively high inductance.

The power card described herein have a lower inductance and a more compact design. There are many contexts in a vehicle where a more compact power card may provide many benefits. For example, when a vehicle has multiple electric motors driving wheels independently (instead of a central electric motor providing power to the wheels), a compact power card at each wheel may be highly beneficial. A compact power card may provide for more efficient and lighter weight systems, as the power card and the motor could share components, such as cooling devices.

The power card described herein may include O lead frames designed to efficiently cool the power devices of the power card. The O lead frame may include cooling channels for passing a liquid to absorb heat. The O lead frame may include a vapor chamber for cooling heat received from the power devices. The O lead frame may also be made of materials having specific thermal conductivity characteristics for improved heat absorption and dissipation.

The power cards described herein may be used with a vehicle. A vehicle is a conveyance capable of transporting a person, an object, or a permanently or temporarily affixed apparatus. The vehicle may have an automatic or manual transmission. The vehicle may be a self-propelled wheeled conveyance, such as a car, sports utility vehicle, truck, bus, van or other motor or battery driven vehicle. For example, the vehicle may be an electric vehicle, a hybrid vehicle, a plug-in hybrid vehicle, a fuel cell vehicle, or any other type of vehicle that includes a motor/generator.

The vehicle may be capable of non-autonomous operation or semi-autonomous operation or autonomous operation. That is, the vehicle may be driven by a human driver or may be capable of self-maneuvering and navigating without human input. A vehicle operating semi-autonomously or autonomously may use one or more sensors and/or a navigation unit to drive autonomously.

FIG. **1**A illustrates a perspective view of a power card **100** having a side-by-side design. The power card **100** includes two power devices **102** located in a co-planar, side-by-side arrangement. The power card **100** also includes an O power terminal **104**, an N power terminal **106**, a P power terminal **108**, and signal terminals **112**. The power card **100** is encased in resin **110**, with the power terminals and signal terminals exposed.

FIG. **1**B illustrates a top-down view of the power card **100** having the side-by-side design. As can be seen in FIG. **1**B, the power terminals **115** (i.e., the O power terminal **104**, the N power terminal **106**, and the P power terminal **108**) and the signal terminals **112** are not entirely encased in resin **110**. In addition, the power terminals **115** are located on a first end **101** of the power card **100**, and the signal terminals **112** are located on a second end **103** of the power card **100**. The power card **100** also includes heat spreaders **114** configured to absorb heat generated by the power devices **102**. Electrical current **116** flows from the P power terminal **108** to the power devices **102**, and through the N power terminal **106**. The O power terminal serves as an output. For example, when the power card is used in conjunction with multiple other power cards in an inverter, the P terminal and N terminal of each power card may be connected to the DC power source, and the O power terminal of each power card is responsible for outputting one phase of the alternating current, with the combined outputs of the O power terminals creating an alternating current. The alternating current may be used to power a motor, for example. When the inverter is bi-directional, alternating current generated by regenerative braking, for example, could be received by the O power terminals of the multiple power cards, and a DC battery may be recharged using the power cards.

FIG. **1**C is a partial side cross-sectional view of the power card **100**. As shown, the power devices **102** are co-planar with each other. One power device **102** is connected to the P power terminal **108** on a first side using solder **118**, and is connected to a conductive copper spacing block **120** on a second side using solder **118**. The conductive copper spacing block **120** is connected to a first heat spreader **114**A using solder **118**. The first heat spreader **114**A has an arm that extends laterally sideways toward the N power terminal **106** and is connected (using solder **118**) to a laterally-extending arm of a second heat spreader **114**B. The second heat spreader **114**B is connected to the other power device **102** using solder **118**. The other power device **102** is connected to the second heat spreader **114**B on a first side using solder **118**, and is connected to a conductive copper spacing block **120** on a second side using solder **118**. The conductive copper spacing block **120** is connected to the N power terminal **106** using solder **118**. Electrical current **116** moves upward from the P power terminal **108**, through a power device **102**, down through the heat spreaders **114**, through the other power device **102**, and through the N power terminal **106**.

FIG. **2**A illustrates a power card **200**. The power card **200** has a chip-on-chip design, where the power devices are located in a vertically stacked arrangement, as compared to the side-by-side design of power card **100**. The chip-on-chip design allows the volume of the power card **200** to be reduced by 49% compared to the power card **100** with the side-by-side design.

The power card **200** includes an O lead frame **204** having a terminal portion **222** extending from a body portion **228** (shown in FIGS. **2**B and **2**E). The power card **200** also includes an N lead frame **206** having a terminal portion **226** extending from a body portion **232**. The power card **200** also includes a P lead frame **208** having a terminal portion **224** extending from a body portion **230**. The terminal portions are configured to connect to other vehicle components to connect the power card **200** to the vehicle. In some embodiments, the body portions of the lead frames may be referred to as the substrate. Electrical current flows from the terminal portion **224** of the P lead frame **208** to the terminal portion **226** of the N lead frame **206**. The terminal portion **222** of the

O lead frame **204** serves as an output. For example, when the power card **200** is used in conjunction with multiple other power cards (similar to power card **200**) in an inverter, the terminal portion **224** of the P lead frame **208** and the terminal portion **226** of the N lead frame **206** of each power card may be connected to the DC power source, and the terminal portion **222** of the O lead frame **204** of each power card is responsible for outputting one phase of the alternating current, with the combined outputs of the terminal portions of the O lead frames of each power card creating an alternating current. The alternating current may be used to power a motor, for example. When the inverter is bi-directional, alternating current generated by regenerative braking, for example, could be received by the terminal portions of the O lead frames of the multiple power cards, and a DC battery may be recharged using the power cards.

The power card **200** has a first end **201** and a second end **203** opposite the first end **201**. The terminal portion **222** of the O lead frame is located at the first end **201** and the terminal portion **226** of the N lead frame and the terminal portion **224** of the P lead frame **208** are located at the second end **203**. By being on opposite ends of the power card **200**, the terminal portions of the O lead frame **204**, the N lead frame **206**, and the P lead frame **208** may be as wide as the power device. In comparison, the power terminals **115** of the side-by-side power card **100** are narrower (approximately half the width of the power device **102**) because the power terminals **115** are all on the same end of the power card **100**. In addition, by having the terminal portion **222** of the O lead frame **204** on the opposite end as the terminal portion **224** of the P lead frame **208** and the terminal portion **226** of the N lead frame **206**, the terminal portion **224** of the P lead frame **208** and the terminal portion **226** of the N lead frame **206** may be located very close to each other and separated by a thin insulator. This close location to each other results in very low inductance for high-speed switching of the power devices.

The power card **200** includes two sets of signal terminals **212**, one set for each of the two power devices. Each set of signal terminals is connected to a respective power device. The set of signal terminals **212** provides connections to the power device, for purposes of providing switching signals to the power device and also for purposes of detecting data from the power device. For example, when there are 5 signal terminals in the set of signal terminals **212**, one signal terminal may connected to the gate of the power device and be used as a gate signal for switching the power device on and off using low voltage, two signal terminals may be used for detecting temperature, one signal terminal may be used as a current sensor, and one signal terminal may be used as an emitter voltage sensor.

The power card **200** also includes voltage terminals **250** as being part of the P lead frame **208**. The voltage terminals **250** may be used to detect a voltage of the power card **200**. The voltage terminals **250** extend away from the body portion **230** of the P lead frame **208**, but in a direction opposite the terminal portion **224** of the P lead frame **208**. Thus, the voltage terminals **250** are located at the first end **201** of the power card **200**, alongside the terminal portion **222** of the O lead frame **204**. The voltage terminals **250** may be located horizontally on either side of the terminal portion **222** of the O lead frame **204**.

The power card **200** has a first lengthwise edge **205** and a second lengthwise edge **207** opposite the first lengthwise edge **205**. As shown in FIG. **2**A, the sets of signal terminals **212** are located at the first lengthwise edge **205** and the voltage terminals **250** are located at the first end **201**. However, in some embodiments, the voltage terminals **250** may be removed and the sets of signal terminals **212** may be reduced to a single signal terminal corresponding to each power device, and these single signal terminals may be located horizontally on either side of the terminal portion **222** of the O lead frame **204**, similar to the location of the voltage terminals **250** in FIG. **2**A.

The power card **200** may be partially encased in resin **210**. The resin **210** may be injection molded to the power card **200** such that all gaps between the components of the power card **200** are occupied with resin **210**. The resin **210** may insulate the components of the power card **200** to allow the power card **200** to operate more efficiently. The terminal portion **222** of the O lead frame **204**, the voltage terminals **250**, portions of the sets of signal terminals **212**, a portion of the terminal portion **224** of the P lead frame, and a portion of the terminal portion **226** of the N lead frame may not be covered in resin **210**, with the remaining components of the power card **200** being encased in resin **210**. The exposed portion of the terminal portion **224** of the P lead frame may be the top surface of the terminal portion **224**. The exposed portion of the terminal portion **226** of the N lead frame may be the bottom surface of the terminal portion **226**.

FIG. **2**B illustrates a top-down view of the power card **200**, with the body portion of the P lead frame **208** made transparent, to show one of the two power devices **202** and a set of signal terminals **212** connected to the power device **202**. The power device **202** may be any switch, such as an RC-IGBT, an IGBT/diode combination, or a MOSFET, for example.

The body portion **228** of the O lead frame **204** is substantially square-shaped and is located in a central portion of the power card **200**, between the first end **201** and the second end **203**. Similarly, the body portion **230** of the P lead frame **208** is substantially square-shaped and is located in a central portion of the power card **200**, between the first end **201** and the second end **203**. In addition, the body portion **232** of the N lead frame **206** is substantially square-shaped and is located in a central portion of the power card **200**, between the first end **201** and the second end **203**.

Between the body portion **228** of the O lead frame **204** and the power device **202** may be a heat spreader **214**. The heat spreader **214** may be formed integrally of the O lead frame **204** at the body portion **228** and may elevate the power device **202** away from the O lead frame **204**. The N lead frame **206** may have a similar heat spreader, as shown in FIG. **2**C.

FIG. **2**C illustrates a partial front cross-sectional view of the power card **200** in a central area of the power card **200** where the body portions of the lead frames and the power devices am located. The N lead frame **206** and the O lead frame **204** have heat spreaders **214** formed integrally in the respective body portions of the N lead frame **206** and the O lead frame **204**. That is, the body portion **232** of the N lead frame **206** has a heat spreader **214** formed integrally in the body portion **232**. The heat spreader **214** extends upward and away from the body portion **232** of the N lead frame **206**. The heat spreader **214** extends in a direction perpendicular to the direction that the terminal portion **226** extends in. The heat spreader **214** may have a tapered shape such that the width of the heat spreader **214** narrows the further away the heat spreader **214** is from the body portion **232** of the N lead frame **206**.

The body portion **232** of the N lead frame **206** connects to a first power device **202**A (via the heat spreader **214**). The body portion **232** of the N lead frame **206** is connected to the first power device **202**A via solder **218**A. The solder **218**A may be applied as a layer between the body portion **232** of the N lead frame **206** and the first power device **202**A or may be applied in discrete areas between the body portion **232** of the N lead frame **206** and the first power device **202**A.

Similarly, the body portion **228** of the O lead frame **204** has a heat spreader **214** formed integrally in the body portion **228**. The heat spreader **214** extends upward and away from the body portion **228** of the O lead frame **204**. The heat spreader **214** extends in a direction perpendicular to the direction that the terminal portion **222** extends in. The heat spreader **214** may have a tapered shape such that the width of the heat spreader **214** narrows the further away the heat spreader **214** is from the body portion **228** of the O lead frame **204**.

The heat spreader **214** may be located on a first side of the body portion **228** of the O lead frame **204**. The first power device **202**A may be connected to the second side of the body portion **228** of the O lead frame **204** using solder **218**B. The solder **218**B may be applied as a layer or in discrete areas. The second side of the body portion **228** of the O lead frame **204** is opposite the first side of the body portion **228** of the O lead frame **204**.

The body portion **228** of the O lead frame **204** connects to a second power device **202**B (via the heat spreader **214**). The body portion **228** of the O lead frame **204** is connected to the second power device **202**B via solder **218**C. The solder **218**C may be applied as a layer between the body portion **228** of the O lead frame **204** and the second power device **202**B or may be applied in discrete areas between the body portion **228** of the O lead frame **204** and the second power device **202**B.

The second power device **202**B is connected to the body portion **230** of the P lead frame **208** using solder **218**D. Unlike the N lead frame **206** and the O lead frame **204**, the P lead frame **208** may not have a heat spreader **214**. Again, the heat spreaders **214** serve to provide space for the signal terminals to connect to the signal pads of the power devices **202**. Without the heat spreaders **214**, there may not be sufficient space for signal terminals to reach the power devices **202**.

As shown in FIG. **2**C, electrical current **216** travels from the P lead frame **208** through the two power devices **202** and through the N lead frame **206**. As compared to electrical current **116** of FIG. **1**C of the side-by-side power card **100**, the electrical current **216** travels in a shorter, straighter line. This makes the operation of the power card **200** more efficient than the power card **100** by reducing self-inductance.

In addition, as compared to the side-by-side power card **100** shown in FIG. **1**C, the power card **200** has fewer components, as the side-by-side power card **100** includes more components that the power card **200** does not include—two conductive copper spacing blocks **120**, two layers of solder **118** connecting each conductive copper spacing block **120** to another component, and a layer of solder between the heat spreaders **114**. In addition, the heat spreaders **114** of the side-by-side power card **100** are bulkier than the integrated heat spreaders **214** of the power card **200**.

FIG. **2**D illustrates a circuit diagram **252** representing the power card **200**.

FIG. **2**E illustrates a side view of components of the power card **200**. The body portion **230** of the P lead frame **208** is aligned with the body portion **228** of the O lead frame **204** as well as the body portion **232** of the N lead frame **206**. In addition, the first power device **202**A is shown as being between the body portion **232** of the N lead frame **206** and the body portion **228** of the O lead frame **204**. The second power device **202**B is shown as being between the body portion **228** of the O lead frame **204** and the body portion **230** of the P lead frame **208**.

The terminal portion **224** of the P lead frame **208** is connected to the body portion **230** of the P lead frame **208** by a bend **234**. The body portion **230** of the P lead frame lies along a P body plane **238** and the terminal portion **224** of the P lead frame **208** lies along a P terminal plane **244**. The P body plane **238** and the P terminal plane **244** are parallel. The bend **234** brings the terminal portion **224** of the P lead frame **208** closer to the N lead frame **206**.

The terminal portion **226** of the N lead frame **206** is connected to the body portion **232** of the N lead frame **206** by a bend **236**. The body portion **232** of the N lead frame lies along an N body plane **240** and the terminal portion **226** of the N lead frame **206** lies along an N terminal plane **246**. The N body plane **240** and the N terminal plane **246** are parallel. The bend **236** brings the terminal portion **226** of the N lead frame **206** closer to the P lead frame **208**.

The distance **254** between the body portion **230** of the P lead frame **208** and the body portion **232** of the N lead frame **206** is greater than the distance **256** between the terminal portion **224** of the P lead frame **208** and the terminal portion **226** of the N lead frame **206** due to the bends **234**, **236**.

An insulator **220** may be located between the terminal portion **224** of the P lead frame **208** and the terminal portion **226** of the N lead frame **206**. The voltage difference between the terminal portion **224** of the P lead frame **208** and the terminal portion **226** of the N lead frame **206** is relatively high. The insulator **220** may be configured to assist in reducing inductance between the P terminal and the N terminal. The insulator **220** may span the entire length of the terminal portion **224** of the P lead frame **208** and the terminal portion **226** of the N lead frame **206**, or may occupy a portion thereof. The insulator **220** may be made of ceramic or any other insulating material. The insulator **220** may be very thin—approximately 320 μm thick. The insulator **220** may occupy the entire distance **256** between the terminal portion **224** of the P lead frame **208** and the terminal portion **226** of the N lead frame **206**.

The body portion **228** of the O lead frame **204** has a top surface that lies along an O plane **242**. The terminal portion **222** of the O lead frame **204** may also lie along the O plane **242** such that a top surface of the body portion **228** of the O lead frame is coplanar to a top surface of the terminal portion **222** of the O lead frame **204**.

The voltage terminals **250** of the P lead frame **208** may extend in a direction opposite the terminal portion **224** of the P lead frame **208**. The voltage terminals **250** may be connected to the body portion **230** of the P lead frame **208** by a bend, and the voltage terminals **250** may lie along the O plane **242**.

FIG. **2**F illustrates an embodiment of the power card **200** without voltage terminals **250** of the P lead frame **208**. The view of FIG. **2**F is a top-down view of the power card **200**, with the body portion of the P lead frame **208** made transparent, to show the second power device **202**B, similar to FIG. **2**B. The first power device **202**A is obscured by the O lead frame **204**.

In embodiments where the voltage terminals **250** are not present, the sets of signal terminals **212** may be replaced by a single signal terminal **260**A for the first power device **202**A and a single signal terminal **260**B for the second power device **202**B. Both of the single signal terminals **260** may lie along the O plane **242**, similar to the previously-present voltage terminals **250**.

The signal terminals **260** may receive signals for switching on and off their respective devices. That is, the first signal terminal **260**A may receive signals for switching on and off the first power device **202**A and the second signal terminal **260**B may receive signals for switching on and off the second power device **202**B.

The power devices **202** may be rotated to allow the contacts of the power devices **202** to be close to the signal terminals **260** and allowing the signal terminals **260** to be as short as possible. While FIG. **2**F illustrates the signal terminals **260** as being on either side of the terminal portion **222** of the O lead frame **204**, the signal terminals **260** may be located at any other location on the power card (e.g., along the lengthwise edges). Also, while FIG. **2**F illustrates the signal terminals **260** as extending outward with a length that is a fraction of the length of the terminal portion **222** of the O lead frame **204**, the signal terminals **260** may be of any length.

FIG. **3**A illustrates a system **300** using the power card **200**. The terminal portion **224** of the P lead frame **208** and the terminal portion **226** of the N lead frame **206** are connected to a capacitor **308** via a P bus bar **304** and an N bus bar **306**, respectively. That is, the P bus bar **304** is connects a second end **340** of the capacitor **308** to the terminal portion **224** of the P lead frame **208**. In particular, a bottom surface of the P bus bar **304** contacts a top surface of the terminal portion **224** of the P lead frame **208**. In addition, the N bus bar **306** connects a first end **342** of the capacitor **308** to the terminal portion **226** of the N lead frame **206**. In particular, a top surface of the N bus bar **306** contacts a bottom surface of the terminal portion **226** of the N lead frame **206**.

The N bus bar **306** has a first portion **330** and a second portion **328**. The first portion **330** connects to the terminal portion **226** of the N lead frame **206**. In particular, a top surface of the first portion **330** of the N bus bar **306** contacts a bottom surface of the terminal portion **226** of the N lead frame **206**. The second portion **328** contacts the first end **342** of the capacitor **308**. The first portion **330** and the second portion **328** both lie along a first plane **336**. The first plane **336** is parallel to the N terminal plane **246**.

The P bus bar **304** has a first portion **322**, a second portion **324**, and a third portion **326**. The first portion **322** connects to the terminal portion **224** of the P lead frame **208**. In particular, the bottom surface of the first portion **322** connects to the top surface of the terminal portion **224** of the P lead frame **208**. The first portion **322** lies along a second plane **334** that is parallel to the P terminal plane **244**. The second plane **334** is also parallel to the first plane **336**.

The second portion **324** of the P bus bar **304** travels up a side of the capacitor **308**. The second portion **324** lies along a third plane **338** perpendicular to the first plane **336** and the second plane **334**.

The third portion **326** of the P bus bar **304** connects to a second end **340** of the capacitor **308**. The third portion **326** lies along a fourth plane **332** that is parallel to the first plane **336** and the second plane **334** and perpendicular to the third plane **338**.

As shown by the arrows, an electrical current flows through the P lead frame **208** (**314**A), through the first portion **322** of the P bus bar **304** (**316**A), through the third portion **326** of the P bus bar **304** (**320**A), through the second portion **328** of the N bus bar **306** (**320**B), through the first portion **330** of the N bus bar **306** (**3168**), and through the N lead frame **206** (**314**B).

Each current flow has a complementary opposite current flow to reduce parasitic inductance. The current flow **314**A is complemented by current flow **314**B, current flow **316**A is complemented by current flow **316**B, current flow **318**A is complemented by current flow **318**B, and current flow **320**A is complemented by current flow **320**B.

FIG. **3**B is a magnified view of the power card **200**. A first heat sink **302**A is connected to the body portion **230** of the P lead frame **208** and a second heat sink **302**B is connected to the body portion **232** of the N lead frame **206**. The heat sinks **302** are configured to cool the respective lead frames.

FIG. **3**C is a perspective view of the system **300**. The power card **200** has a width **312**, and the P bus bar **304**, the N bus bar **306**, and the capacitor **308** have a width **310**. The width **310** may be as wide as the application of the system **300** will allow, in order to reduce current density through the P bus bar **304**, the N bus bar **306**, and the capacitor **308**. The terminal portions of the N lead frame **206**, the P lead frame **208**, and the O lead frame **204** may also be as wide as possible to reduce current density. As compared to the N power terminal **106**, the P power terminal **108**, and the O power terminal **104**, the terminal portions of the N lead frame **206**, the P lead frame **208**, and the O lead frame **204** are at least twice as wide. The N power terminal **106**, the P power terminal **108**, and the O power terminal **104** may be half the width of the power device, and the terminal portions of the N lead frame **206**, the P lead frame **208**, and the O lead frame **204** may be as wide as the power device.

Simulations of the systems described herein using power card **200** demonstrate a significant decrease in inductance compared to the power card **100**. The inductance from the power card **200** is 1.90 nH, compared to 19.3 nH of the power card **100**. Thus, the power card **200** reduces inductance by 90% and volume by 49% compared to power card **100**.

FIGS. **4**A-**4**D illustrate a process of manufacturing the power card **200**. FIG. **4**A shows a power device **202** having signal pads **402**. The signal pads **402** are configured to connect to signal terminals of a set of signal terminals (e.g., set of signal terminals **212**). Solder **403** is applied to the signal pads **402**.

FIG. **48** illustrates solder being applied to the O lead frame **204** and the N lead frame **206**. The O lead frame **204** and the N lead frame **206** are placed in a lower moat **408** and an upper moat **406** is removably placed on top of the O lead frame **204** and the N lead frame **206**. In particular, the O lead frame **204** is placed in and received by a cavity **416** formed in the lower moat **408**, and the N lead frame **206** is placed in and received by a cavity **414** formed in the lower moat **408**. A first side (or "top side" or "upper side") **458** of the O lead frame **204** contacts the upper most **406** and a second side (or "bottom side" or "lower side") **460** of the O lead frame **204** contacts the lower moat **408**. Similarly, a first side (or "top side" or "upper side") **452** of the N lead frame **206** contacts the upper moat **406** and a second side (or "bottom side" or "lower side") **454** of the N lead frame **206** contacts the lower moat **408**.

The O lead frame **204** has an elevated heat spreader **214** formed integrally in the body portion **228** of the O lead frame **204**. Similarly, the N lead frame **206** has an elevated heat spreader **214** formed integrally in the body portion **232** of the N lead frame **206**. The elevated heat spreader **214** of the O lead frame **204** has a surface **456** and the elevated heat spreader **214** of the N lead frame **206** also has a surface **450**.

When the O lead frame **204** and the N lead frame **206** are located between the upper moat **406** and the lower moat **408**, the surface **456** of the O lead frame **204** and the surface **450** of the N lead frame **206** are exposed via an O lead frame opening **410** and an N lead frame opening **412**, respectively, of the upper moat **406**. When the surface **456** of the O lead frame **204** and the surface **450** of the N lead frame **206** are exposed, solder **418** may be applied to the surface **456** of the O lead frame **204** and the surface **450** of the N lead frame **206**.

Similarly, when the O lead frame **204** and the N lead frame **206** are located between the upper moat **406** and the lower moat **408**, portions of the body portions of the O lead frame **204** and the N lead frame **206** may be exposed via openings **428** of the upper moat **406**. Solder **404** may be applied to the exposed portions of the body portions of the O lead frame **204** and the N lead frame **206** via the openings **428** of the upper moat **406**.

The upper moat **406**, lower moat **408**, the O lead frame **204**, the N lead frame **206**, and the solder **404**, **418** are heated so that the solder **404**, **418** attaches to its respective contacting surfaces on the O lead frame **204** and the N lead frame **206**. The solder **418** will be used to couple the respective lead frame to a respective power device **202**, and the solder **404** will be used to secure a respective set of signal terminals **212** to the respective lead frame.

Once the solder has cooled and set, the upper moat **406** is removed, and the O lead frame **204** and the N lead frame **206** are removed from the lower moat **408**.

FIG. **4**C illustrates power devices **202** being connected to the O lead frame **204** and the N lead frame **206**. As compared to FIG. **4**B, the O lead frame **204** and the N lead frame **206** are turned upside down, such that the first side **458** of the O lead frame **204** faces downward and the second side **460** of the O lead frame **204** faces upward, and the first side **452** of the N lead frame **206** faces downward and the second side **454** of the N lead frame **206** faces upward.

A moat **420** has a first cavity **422** for receiving solder **426** and a second cavity **424** also for receiving solder **426**. A first power device **202**A is placed on top of the solder **426** in the first cavity **422**. More specifically, a second side **482** of the first power device **202**A contacts the solder **426**.

The N lead frame **206** is placed on top of the first side **480** of the first power device **202**A. The solder **418** on the first side **452** of the N lead frame **206** contacts the first side **480** of the first power device **202**A and couples the first power device **202**A to the N lead frame **206**.

Sandwiched between the first power device **202**A and the N lead frame **206** is a set of signal terminals **212**. The set of signal terminals **212** has a plurality of signal terminals **466** and a set of testing terminals **464** used to test the power card. The signal terminals **466** of the set of signal terminals **212** are connected to the signal pads **402** of the first power device **202**A using solder **403**. The testing terminals **464** are connected to the body portion **232** of the N lead frame **206** via solder **404**. In some embodiments, there are no testing terminals **464**, and only signal terminals **466**. In some embodiments, there is only one signal terminal instead of the set of signal terminals, where the single signal terminal is a gate signal used for switching the first power device **202**A on and off.

A second power device **202**B is placed on top of the solder **426** in the second cavity **424**. More specifically, a second side **482** of the second power device **202**B contacts the solder **426**.

The O lead frame **204** is placed on top of the first side **480** of the second power device **202**B. The solder **418** on the first side **458** of the O lead frame **204** contacts the first side **480** of the second power device **202**B and couples the second power device **202**B to the O lead frame **204**.

Sandwiched between the second power device **202**B and the O lead frame **204** is a set of signal terminals **212**. The set of signal terminals **212** has a plurality of signal terminals

466 and a set of testing terminals **464** used to test the power card. The signal terminals **466** of the set of signal terminals **212** are connected to the signal pads **402** of the second power device **202**B using solder **403**. The testing terminals **464** are connected to the body portion **228** of the O lead frame **204** via solder **404**. In some embodiments, them are no testing terminals **464**, and only signal terminals **466**. In some embodiments, there is only one signal terminal instead of the set of signal terminals, where the single signal terminal is a gate signal used for switching the second power device **202**B on and off.

All of the components are heated so that the solder can attach to its respective contacting surfaces. The N lead frame **206** having the first power device **202**A attached to it and the O lead frame **204** having the second power device **202**B attached to it are removed from the moat **420** once the solder has cooled and set.

FIG. **4**D illustrates the P lead frame **208**, the O lead frame **204**, and the N lead frame **206** being combined into the power card **200**. The moat **468** has a cavity **470** configured to receive the N lead frame **206**. In particular, the second side **454** of the N lead frame **206** contacts the cavity **470** of the moat **468**. The first side **452** of the N lead frame **206** faces the second side **460** of the O lead frame **204**. The second side **482** of the first power device **202**A faces the second side **460** of the O lead frame **204** and connects to the body portion **228** of the O lead frame **204** via solder **426**.

The first side **458** of the O lead frame **204** faces the second side **474** of the P lead frame **208**. The second side **482** of the second power device **202**B faces the second side **474** of the P lead frame **208** and connects to the body portion **230** of the P lead frame **208** via solder **426**. The first side **472** of the P lead frame **208** faces upward.

All of the components are heated so that the solder can attach to its respective contacting surfaces. A spacer **476** may temporarily be disposed between the two sets of signal terminals **212** to provide support for the sets of signal terminals **212** while the solder connecting the sets of signal terminals **212** to the lead frame and power device cools and sets. An insulator **220** may be disposed between the terminal portion **224** of the P lead frame **208** and the terminal portion **226** of the N lead frame **206**.

Once the solder has set, the spacer **476** is removed, and the intermediate assembly including the P lead frame **208**, the O lead frame **204**, the N lead frame **206**, the first power device **202**A, the second power device **202**B, the sets of signal terminals **212**, and the solder disposed therebetween, may be placed in a mold. The resin **210** may be injected into the mold such that the resin **210** fills all gaps between components of the intermediate assembly. Once the resin **210** is cured, additional finishing steps (e.g., cutting the resin to expose metal parts on the top and bottom of the power card, signal terminal cutting, cleaning) may be performed, and the power card **200** fabrication is complete.

As described herein, the resin **210** may not cover all of the components of the power card **200**. In particular, the resin **210** may not cover the terminal portion **222** of the O lead frame **204**, the top surface of the terminal portion **224** of the P lead frame **208** (e.g., the terminal portion **224** of the first side **472** of the P lead frame **208**), and the bottom surface of the terminal portion **226** of the N lead frame **206** (e.g., the terminal portion **226** of the second side **454** of the N lead frame **206**).

Any of the moats (e.g., upper moat **406**, lower moat **408**, moat **420**, moat **468**) may be made of graphite or other similar durable materials. The moats may also have any number of support features for supporting and framing the components received in the moat cavity, as shown in FIGS. 4B-4D.

Because of the stacked arrangement of the power devices **202**, the power card **200** may generate significant amounts of heat. In some embodiments, cooling may be provided on both sides of each power device **202** to improve the cooling of the power card **200**. When the power card **200** is not sufficiently cooled, thermal resistivity may rise, and the power card **200** may not operate as efficiently.

FIG. **5**A illustrates a side view of a power card **500** having an O lead frame **504** with integrated cooling. The power card **500** is similar to power card **200** described herein. Components of power card **200** that are different in power card **500** may be numbered with different reference numbers than those used with respect to power card **200**.

Power card **500** includes P lead frame **208**, N lead frame **206**, a first power device **202**A, a second power device **202**B, a single signal terminal **260**A for the first power device **202**A, a single signal terminal **260**B for the second power device **202**B, a first heat sink **302**A, and a second heat sink **302**B, each as described herein. These components, along with the O lead frame **504** are encased in resin **210**, as described herein.

The O lead frame **504** has a body portion **506** and a terminal portion **508** extending outward from the body portion **506**. The first power device **202**A is coupled to a first side **554** of the O lead frame **504** (specifically, the body portion **506** of the O lead frame) and the second power device **202**B is coupled to a second side **556** of the O lead frame **504** (specifically, the body portion **506** of the O lead frame).

The body portion **506** of the O lead frame **504** includes an O channel **502**, which may be one or more channels. The O channel **502** is configured to receive cooling liquid and allow the cooling liquid to pass through the O channel **502**. When the cooling liquid is within the O channel **502**, the cooling liquid absorbs heat emitted from the first power device **202**A and the second power device **202**B. The now-heated cooling liquid exits the O channel **502** to be cooled, and as the now-heated cooling liquid exits the O channel **502**, new, cooler cooling liquid takes its place in the O channel **502** for absorbing heat. The cooling liquid may be any liquid capable of being heated and cooled efficiently, such as dielectric coolant or oil.

The combination of the heat sinks **302** and the O lead frame **504** with channels **502** provides cooling to both sides of each power device **202**. That is, the first power card **202**A is cooled on a first side by the second heat sink **302**B and on a second side by the O lead frame **504**, and the second power card **202**B is cooled on a first side by the O lead frame **504** and on a second side by the first heat sink **302**A.

FIG. **5**B illustrates the power card **500** with a manifold **512** located around a central portion of the power card **500**. The central portion of the power card **500** may be delineated by the body portions of the P lead frame **208**, the N lead frame **206**, and the O lead frame **504** along a centerline axis **538** of the power card **500**.

The manifold **512** may surround and encase a central portion of the power card **500**, wrapping around the central portion of the power card **500**, to form multiple fluidly coupled channels, including the O channel **502**. The multiple channels may include a top channel **514** and a bottom channel **516**. The top channel **514** may be located radially outward of the body portion **230** of the P lead frame **208**, relative to the centerline axis **538**. The bottom channel **516** may be located radially outward of the body portion **232** of the N lead frame **206**, relative to the centerline axis **538**. The top channel **514** and the bottom channel **516** may each be defined by an interior surface of the manifold **512** and an exterior of the power card **500**.

Further, the top channel **514** may be a plurality of channels defined by the tins **552** of the first heat sink **302**A, and the bottom channel **516** may be a plurality of channels defined by the fins **552** of the second heat sink **302**B. That is, the top channel **514** may be a plurality of channels having a bottom and side surface defined by the fins **552** of the first heat sink **302**A and a top surface defined by an interior surface of the manifold **512**, and the bottom channel **516** may be a plurality of channels having a top and side surface defined by the fins **552** of the second heat sink **302**B and a bottom surface defined by an interior surface of the manifold **512**. The top channel **514** and the bottom channel **516** may lie on planes that are parallel to the planes that the lead frames lie on.

The top channel **514** is configured to receive cooling liquid and allow the cooling liquid to pass through the top channel **514**. When the cooling liquid is within the top channel **514**, the cooling liquid absorbs heat emitted from the second power device **202**B and the first heat sink **302**A. The now-heated cooling liquid exits the top channel **514** to be cooled, and as the now-heated cooling liquid exits the top channel **514**, new, cooler cooling liquid takes its place in the top channel **514** for absorbing heat.

The bottom channel **516** is configured to receive cooling liquid and allow the cooling liquid to pass through the bottom channel **516**. When the cooling liquid is within the bottom channel **516**, the cooling liquid absorbs heat emitted from the first power device **202**A and the second heat sink **302**B. The now-heated cooling liquid exits the bottom channel **516** to be cooled, and as the now-heated cooling liquid exits the bottom channel **516**, new, cooler cooling liquid takes its place in the bottom channel **516** for absorbing heat.

The manifold **512** also includes an inlet port **510** for receiving the cooling liquid for passing through the O channel **502**, the top channel **514**, and the bottom channel **516**. A vertically oriented inlet side channel **520** may fluidly connect the inlet port to the top channel **514** and the bottom channel **516**, allowing the cooling liquid to flow **518** to the top channel **514** and the bottom channel **516** when received via the inlet port **510**. The resin **210** encasing the power card **500** prevents the cooling liquid from contacting components of the power card **500** other than the O channel **502**, the top channel **514**, and the bottom channel **516**. In particular, the cooling liquid does not contact the power devices **202** or the P lead frame **208** or the N lead frame **206**.

The manifold **512** also includes an outlet port on an opposite side of the inlet port **510** for expelling the used cooling liquid from the O channel **502**, the top channel **514**, and the bottom channel **516**. A vertically oriented outlet side channel may fluidly connect the outlet port to the top channel **514** and the bottom channel **516**.

The top channel **514**, bottom channel **516**, inlet side channel **520**, and outlet side channel may span substantially the entire length of the manifold **512** or may span a portion of the manifold **512**. The O channel **502**, the top channel **514**, and the bottom channel **516** may span substantially the entire width of the manifold **512**. The top channel **514**, bottom channel **516**, inlet side channel **520**, and outlet side channel may include multiple channels or may be single respective channels.

The manifold **512** may also include a front face **540** and a rear face **542** that are parallel to each other and perpendicular to the respective planes that the top channel **514**, bottom channel **516**, inlet side channel **520**, and outlet side channel lie on.

Since the cooling is direct liquid cooling, heat from the power devices **202** will be absorbed by the cooling liquid and the heat will not pass through the manifold **512**. Thus, the manifold **512** may be made of a non-thermally/electrically conductive material, such as PEEK or plastic. The insulated manifold material and use of a dielectric coolant reduce the possibility for a short circuit.

FIG. **5**C illustrates a perspective view of the power card **500** shown in FIG. **5**B. In particular, FIG. **5**C shows the outlet port **528** and the outlet side channel **522**. The manifold **512** spans a lengthwise periphery **558** of the body portion **232** of the N lead frame **206**, the body portion **230** of the P lead frame **208**, and the body portion **506** of the O lead frame **504**.

The inlet port **510** is coupled to an inlet tube **524**. The inlet tube **524** connects to a cooling device that provides the cooling liquid to flow **518** through the channels of the manifold and the channels of the O lead frame **504**. The outlet port **528** is coupled an outlet tube **526**. The outlet tube **526** connects to the cooling device that receives the used cooling liquid that flowed through the channels of the manifold and the channels of the O lead frame **504** and absorbed heat from the first power device **202**A and the second power device **202**B. The cooling device cools the used cooling liquid and provides the cooled cooling liquid to the manifold **512** via the inlet tube **524**.

While the inlet port **510** and the inlet tube **524** are shown as being on the first lengthwise edge **534** and the outlet port **528** and the outlet tube **526** are shown as being on the second lengthwise edge **536**, in other embodiments, the inlet port **510** and the inlet tube **524** may be on the second lengthwise edge **536** and the outlet port **528** and the outlet tube **526** may be on the first lengthwise edge **534**. In other embodiments, the inlet port **510** and the inlet tube **524** may be on another surface of the manifold **512** and the outlet port **528** and the outlet tube **526** may be on yet another surface of the manifold **512**.

As the inlet port **510**, inlet tube **524**, outlet port **528**, and outlet tube **526** occupy the lengthwise edges of the power card **500**, (e.g., signal terminals **212** of FIGS. **2**A-**2**B) may not be located on either lengthwise edge, and single signal terminals **260** for each of the power devices **202** are located on either side of the terminal portion of the O lead frame.

FIG. **5**D is a block diagram of a system **550** using the power card **500**. The power card **500** is connected to the manifold **512**, as described herein. The manifold **512** is connected to a liquid cooler **530**, which provides cooled cooling liquid to the manifold **512** and receives used cooling liquid from the manifold **512**. The liquid cooler **530** cools the used cooling liquid and provides the cooled liquid to the manifold **512**. The liquid cooler **530** may cool the used cooling liquid using a radiator, for example.

The liquid cooler **530** is also connected to a vehicle device **532** and circulates cooling liquid to the vehicle device **532** to cool components of the vehicle device **532**. The vehicle device **532** may be any vehicle component that generates heat, such as an electronic control unit, a motor, a brake, or an engine, for example. By using a single liquid cooler **530** across multiple devices (e.g., power card **500** and vehicle device **532**), the vehicle is able to reduce complexity, cost, weight, and maintenance demand, among other things.

When the vehicle device **532** is a motor powering a wheel of a vehicle, the system **550** may be sufficiently compact to be located proximal to the wheel of the vehicle. The vehicle may include additional similar systems **550** for each wheel.

FIG. **6** illustrates an O lead frame **604** similar to O lead frame **504**. The O lead frame **604** includes a plurality of channels **602** (similar to O channel **502**) for receiving cooling liquid. The channels **602** may be formed in the body portion **606** (similar to body portion **506**) of the O lead frame **604**. The O lead frame **604** may also include a terminal portion **608** (similar to terminal portion **508**) extending from the body portion **606**.

The channels **602** may span a width of the O lead frame **604**. The channels **602** may each have the same cross-sectional area, or the channels **602** may have varying cross-sectional areas. The channels **602** may be straight lines through the width of the O lead frame **604** or may be curved paths traversing the body portion **606** of the O lead frame **604**.

The channels **602** may be formed integrally in the body portion **606** of the O lead frame **604**. The channels **602** may be etched or machined out of a solid O lead frame **604**. The channels **602** may be cast using a mold that includes the channels **602**. In other embodiments, the O lead frame may be constructed using multiple pieces.

FIG. **7** illustrates an O lead frame **704** similar to O lead frame **504**. The O lead frame **704** includes a plurality of channels **702** (similar to O channel **502**) for receiving cooling liquid. The channels **702** may be formed in the body portion **706** (similar to body portion **506**) of the O lead frame **704**. The O lead frame **704** may also include a terminal portion **708** (similar to terminal portion **508**) extending from the body portion **706**.

The channels **702** may span a width of the O lead frame **704**. The channels **702** may each have the same cross-sectional area, or the channels **702** may have varying cross-sectional areas. The channels **702** may be straight lines through the width of the O lead frame **704** or may be curved paths traversing the body portion **706** of the O lead frame **704**.

The O lead frame **704** may be made of two components—a top portion **714** and a bottom portion **712**. The top portion **714** includes the terminal portion **708** and the channels **702** formed integrally within the top portion **714**. The bottom portion **712** is substantially flat and forms the base of the O lead frame **704**. The bottom portion **712** may be attached to the top portion **714** along a front edge **716** and a rear edge **718** using solder **710**.

When the O lead frame is a single piece, such as O lead frame **604**, manufacture of a power card **500** is similar to the manufacture of power card **200**, as described in FIGS. **4**A-**4**D. The primary changes would be manufacture of the O lead frame **504** described herein and a modified mold for the resin **210**.

When the O lead frame is made of multiple pieces, such as O lead frame **704**, manufacture of a power card **500** may be made simpler than the process described in FIGS. **4**A-**4**D. The top portion **714** may be substituted for the O lead frame **204** as shown in FIGS. **4**B and **4**C and described herein. Then, instead of performing a solder reflow process of the entire power card, as shown in FIG. **4**D, a first sub-card and second sub-card are fabricated.

The first sub-card has the P lead frame **208**, the second power device **202**B, a single signal terminal **260**, the top portion **714** of the O lead frame **704**, and solder located between the P lead frame **208** and the second power device **202**B, solder located between the second power device **202**B and the top portion **714** of the O lead frame **704**, and solder connecting a contact pad of the second power device **202**B to the single signal terminal **260**. The components of the first sub-card may be soldered together using a moat and heating the first sub-card in the moat, to create reflow soldering.

The second sub-card has the N lead frame **206**, the first power device **202**A, a single signal terminal **260**, the bottom portion **712** of the O lead frame **704**, and solder located between the N lead frame **206** and the first power device **202**A, solder located between the first power device **202**A and the bottom portion **712** of the O lead frame **704**, and solder connecting a contact pad of the first power device **202**A to the single signal terminal **260**. The components of the second sub-card may be soldered together using a moat and heating the second sub-card in the moat, to create reflow soldering.

The first sub-card and the second sub-card may then be connected using solder **710**, as shown in FIG. **7** to complete fabrication of the power card.

In addition to or in lieu of the O lead frame **504** with the O channel **502**, the O lead frame may be made of a material with thermal conductivity properties that allow for more efficient cooling of the O lead frame, and therefore mom efficient cooling of the power devices **202**.

FIG. **8** illustrates a power card **800** that has a thermally conductive O lead frame **804**. The O lead frame **804** has a body portion **806** and a cooling portion **808** extending from the body portion **806** toward a first end **820** of the power card **800**. The cooling portion **808** is connected to the body portion **806** and cools the body portion **806**. The power card **800** is similar to power card **200** described herein. Components of power card **200** that are different in power card **800** may be numbered with different reference numbers than those used with respect to power card **200**.

Power card **800** includes a P lead frame **208** (with a body portion **230**), an N lead frame **206** (with a body portion **232**), a first power device **202**A, a second power device **202**B, and resin **210** encasing the components of the power card **800**, as described herein. The N lead frame **206** and the P lead frame **208** have respective terminal portions extending from their respective body portions and toward a second end **818** of the power card **800**.

The first power device **202**A and the second power device **202**B generate heat **810** as they operate. In particular, the heat generated from the first power device **202**A passes through the body portion **230** of the P lead frame **208**, and the heat generated from the second power device **202**B passes through the body portion **232** of the N lead frame **206**. The heat from both the first power device **202**A and the second power device **202**B may be encountered by the body portion **806** of the O lead frame **804**. The heat encountered by the O lead frame **804** may be absorbed by the body portion **806** and cooled using the cooling portion **808**.

The O lead frame **804** may be made of a highly thermally conductive material, so that the heat is efficiently conducted from the body portion **806** to the cooling portion **808**. The cooling portion **808** may have a relatively large surface area for releasing the conducted heat. In particular, the cooling portion **808** may have a top surface **822** and a bottom surface **824** located radially outward of the top and bottom surfaces of the body portion **806** of the O lead frame **804**, and also multiple side surfaces **826** extending between the top surface **822** and the bottom surface **824** of the cooling portion **808** of the O lead frame **804**. The multiple side surfaces **826** are perpendicular to the top surface **822** and the bottom surface **824**. The side surfaces **826**, the top surface **822**, and the bottom surface **824** create a relatively large surface area for cooling heat **810** received by the body portion **806** of the O lead frame **804**.

The top surface **822** may be coplanar with a radially outermost surface **832** of the P lead frame **208** (e.g., the first side **472** of the P lead frame **208**). The bottom surface **824** may be coplanar with a radially outermost surface **834** of the N lead frame **206** (e.g., second side **454** of the N lead frame **206**). As such, the cooling portion **808** of the O lead frame **804** may be non-overlapping with the body portions of the P lead frame **208** and the N lead frame **206**.

In some embodiments, the cooling portion **808** is also attached to separate cooling devices, such as heat sinks or liquid cooling devices to further improve cooling.

FIG. **9** illustrates an O lead frame **804** made of graphite. The thermal conductivity of graphite is not homogeneous. Graphite has high thermal conductivity in two axes, but low thermal conductivity along a third axis. The thermal conductivity properties of the O lead frame **804** is shown on the 3-dimensional axes as k_{xx}, k_{yy}, and k_{zz}. The thermal conductivity along the lengthwise axis of the O lead frame (e.g., axis **538**) is represented by k_{xx}. The thermal conductivity along the widthwise axis of the O lead frame **804** is represented by k_{yy}. The thermal conductivity along the vertical axis of the O lead frame **804** is represented by k_{zz}. The O lead frame **804** may be made so that the two axes of the graphite with high thermal conductivity are k_{xx} and k_{zz} and the axis with low thermal conductivity is k_{yy}.

As shown in FIG. **10**, heat **812**A received by the body portion **806** of the O lead frame **804** from the first power device **202**A and the heat **812**B received by the body portion **806** of the O lead frame **804** from the second power device **202**B are easily absorbed by the O lead frame **804** (along the k_{zz} axis). The heat **814** is efficiently directed toward the cooling portion **808** (along the k_{xx} axis) which is cooler than the body portion **806**. The heat **816**A is then directed (along the k_{zz} axis) to the bottom surface **824** (or attached cooling device) and the heat **816**B is directed (along the k_{zz} axis) to the top surface **822** (or attached cooling device). The heat **814** may also continue to the side surfaces **826** (along the k_{xx} axis).

A thickness **828** of the cooling portion **808** may be greater than a thickness **830** of the body portion **806**. The increased thickness and the greater surface area described herein contribute to the cooling capabilities of the cooling portion **808**.

FIG. **11** illustrates an O lead frame **1104** made of a combination of two materials. The O lead frame **1104** has a body portion **1106**, a cooling portion **1108**, a power device platform **1102**, and a transition portion **1110**. The body portion **1106** and the cooling portion **1108** are similar to body portion **806** and cooling portion **808** described herein.

The platform **1102** is configured to contact power devices **202** on either side of the platform **1102**. That is, the platform **1102** has a first side **1112**A configured to contact a first power device **202**A and a second side **1112**B opposite the first side **1112**A and configured to contact a second power device **202**B. FIG. **11** shows the second side **1112**B of the platform **1102** and the elevation of the platform **1102** from the rest of the body portion **1106**. Similarly, the platform **1102** is elevated from the rest of the body portion **1106** on the first side **1112**A.

The transition portion **1110** may be optional and connects the platform **1102** to the body portion **1106**. In some embodiments, the transition portion **1110** spans the thickness of the body portion **1106**, such that the transition portion **1110** occupies an aperture in the body portion **1106**. In other embodiments, the transition portion **1110** is located on top of the body portion **1106** on the top and bottom surfaces of the body portion **1106**. In other embodiments, the transition portion **1110** spans a portion of the thickness of the body portion **1106**, such that the transition portion **1110** occupies a cavity in the body portion **1106** on the top and bottom surfaces of the body portion **1106**.

When the platform **1102** and the transition portion **1110** are made of the same material, the platform **1102** may be formed integrally with the transition portion **1110**. When the platform **1102** and the transition portion **1110** are made of different materials, the platform **1102** may be located on top of the transition portion **1110** on the top and bottom surfaces of the transition portion **1110**, or platform **1102** may occupy a cavity in the transition portion **1110** on the top and bottom surfaces of the transition portion **1110**.

The body portion **1106** and the cooling portion **1108** may be made of a first material (e.g., graphite) and the platform **1102** and transition portion **1110** may be made of a second material (e.g., copper). The first material may have a greater thermal conductivity than the second material. As a result, if the power devices **202** were to generate heat unevenly (e.g., "local hot spots"), the uneven heat would be spread across the platform **1102** and the transition portion **1110** before reaching the body portion **1106**. The uneven heat is spread across the platform **1102** and the transition portion **1110** more than if the platform **1102** were also made of the first material. Once the heat reaches the body portion **1106** made of the first material, the heat would be conducted as shown in FIG. **10** and described herein.

The body portion **1106**, the cooling portion **1108**, and the transition portion **1110** may be made of a first material (e.g., graphite) and the platform **1102** may be made of a second material (e.g., copper). The first material may have a greater thermal conductivity than the second material. As a result, if the power devices **202** were to generate heat unevenly (e.g., "local hot spots"), the uneven heat would be spread across the platform **1102** before reaching the transition portion **1110** and the body portion **1106**. The uneven heat is spread across the platform **1102** more than if the platform **1102** were also made of the first material. Once the heat reaches the body portion **1106** made of the first material, the heat would be conducted as shown in FIG. **10** and described herein.

The body portion **1106** and the cooling portion **1108** may be made of a first material (e.g., graphite), the platform **1102** may be made of a second material (e.g., copper), and the transition portion **1110** may be made of a third material. The first material may have a greater thermal conductivity than the second material and the third material. As a result, if the power devices **202** were to generate heat unevenly (e.g., "local hot spots"), the uneven heat would be spread across the platform **1102** and the transition portion **1110** before reaching the body portion **1106**. The uneven heat is spread across the platform **1102** and the transition portion **1110** more than if the platform **1102** or the transition portion **1110** were also made of the first material. Once the heat reaches the body portion **1106** made of the first material, the heat would be conducted as shown in FIG. **10** and described herein.

In some embodiments, the third material has a greater thermal conductivity than the second material, to transition the heat flow from the second material to the first material. In other embodiments, the third material has a lower thermal conductivity than the second material to further spread out the heat across the transition portion **1110**.

In some embodiments, the O lead frame **1104** is similar to O lead frame **804** and made of the first material, but is coated with the second material. Thus, instead of the platform **1102** being made of the second material, the entire surface of the O lead frame **1104** is coated with the second material. In these embodiments, the mechanical rigidity of the O lead frame **1104** may increase.

In some embodiments, the platform **1102** is divided into two pieces, with a first piece coupled to a first side of the body portion **1106** of the O lead frame **1104** and also coupled to a first power device, and a second piece coupled to a second side of the body portion **1106** of the O lead frame **1104** and also coupled to a second power device.

In other embodiments, the platform **1102** is a single piece having a first side **1112**A and a second side **1112**B, and the platform **1102** spans the thickness of the body portion **1106** and is located within an aperture of the body portion **1106** of the O lead frame **1104**.

In some embodiments, the O lead frame has an integrated vapor chamber or heat pipe to improve cooling. FIG. **12** illustrates an example heat pipe **1204**. The heat pipe **1204** is hollow and has an evaporator **1202** located on a top surface **1210**, a vapor portion **1206**, and a condenser **1208** located won a bottom surface **1212**. The evaporator **1202** is connected to the heat source (e.g., the power devices **202**). The evaporator contains liquid that is heated by the heat source. The heated liquid is vaporized by the heat and heated vapor travels through the vapor portion **1206** to the condenser **1208**.

The heated vapor cools as it contacts the condenser **1208**. The cooled vapor condenses on the interior walls of the condenser **1208** and turns to liquid. The liquid travels back to the evaporator **1202**, where the process will be repeated. The heating, vaporization, cooling, and condensing of the liquid in the heat pipe **1204** is an efficient way to provide cooling to the heat source.

FIG. **13** illustrates a cross-sectional view of a vapor chamber **1304** using similar principles as the heat pipe **1204**. The evaporator **1302** of the vapor chamber **1304** receives heat **1322** from a heat source (e.g., power devices **202**) via a first plate **1336** and a second plate **1338**. The heat **1322** heats and vaporizes liquid in the vapor chamber **1304**, resulting in vapor generation **1330**. The vapor flows to the center of the vapor chamber **1304** and travels **1340** along the adiabatic section **1334**. The vapor condenses **1332** as the heat is released **1324** along the first plate **1336** and the second plate **1338** in the condenser **1308**. The condensation **1332** is absorbed by a wick **1328** lining the interior walls of the vapor chamber **1304**. The condensed vapor turns to liquid and returns **1326** to an area near the evaporator **1302**, and the process continues.

FIGS. **14**A and **14**B illustrate an O lead frame **1404** with an integrated vapor chamber similar to heat pipe **1204** and vapor chamber **1304**. FIG. **14**A is a side view of the power card with the O lead frame **1404** and FIG. **14**B is a top view of the power card with the O lead frame **1404**.

As shown in FIG. **14**A, the O lead frame **1404** includes a body portion **1406** and a cooling portion **1408** extending from the body portion **1406**. The O lead frame **1404** has an interior cavity. The body portion **1406** includes an evaporator **1402** and the cooling portion **1408** includes a condenser **1418**. Lining the interior cavity of the O lead frame **1404** is a wick **1422**. The evaporator **1402** and the condenser **1418** are in fluid communication.

The power devices **202**A and **202**B, which are coupled to the body portion **1406** of the O lead frame **1404**, heat liquid within the evaporator **1402** and the liquid vaporizes. The vapor **1420** moves to the condenser **1418** of the cooling portion **1408**. The vapor **1420** cools as heat from the vapor is dissipated by the walls of the condenser **1418** and the vapor condenses into a liquid along one or more interior surfaces of the condenser **1418**. The condensed vapor (now a liquid) is absorbed by the wick **1422** and returned to the evaporator **1402**. The process repeats and allows the O lead frame **1404** to provide cooling to the power devices **202**A and **202**B.

FIG. **14**B illustrates the vapor flow **1410** of the vapor **1420** moving from the evaporator **1402** to the condenser chamber **1418** of the cooling portion **1408**.

FIG. **15** illustrates an O lead frame **1504** having a body portion **1506** and multiple cooling portions **1508** extending from the body portion **1506**. In particular, a first cooling portion **1508**A extends along the length of the power card that the O lead frame **1504** is used in. A second cooling portion **1508**B extends in a first side direction along the width of the power card. A third cooling portion **1508**C extends in a second side direction along the width of the power card. Thus, the second cooling portion **1508**B and the third cooling portion **1508**C may be on opposite sides of the O lead frame **1504**, and may each extend in directions perpendicular to the direction the first cooling portion **1508**A extends in.

The body portion **1506** includes an evaporator **1502** similar to evaporator **1402**. The cooling portions **1508** each include respective condensers **1518** for cooling the vapor created by the heat from the power devices that are coupled to the body portion **1506**. In particular, the first cooling portion **1508**A has a first condenser **1518**A, the second cooling portion **1508**B has a second condenser **1518**B, and the third cooling portion **1508**C has a third condenser **1518**C. Each condenser **1518** is fluidly coupled to the evaporator **1502** to receive vapor from the evaporator and to send condensed liquid via an internal wick (e.g., wick **1422**).

The additional cooling portions of the O lead frame **1504**, as compared to the O lead frame **1404**, may allow the O lead frame **1504** to more efficiently dissipate heat generated by the power devices. The O lead frame **1504** may be used with power cards that do not have a set of signal terminals on the side of the power card, such as power card **200** illustrated in FIG. **2**F. While three discrete cooling portions are illustrated in FIG. **15**, in some embodiments, there may be more cooling portions (e.g., 6 cooling portions, 9 cooling portions, etc.) or there may be one continuous cooling portion spanning a perimeter of the O lead frame **1504** on three sides of the body portion **1506**.

In some embodiments, the cooling portions **808**, **1108**, **1408**, **1508** may be referred to as terminal portions. In some embodiments, any of the O lead frames described herein may be made of a material having high thermal conductivity in two axes, but low thermal conductivity along a third axis, for improving the cooling capabilities of the O lead frame. Except as noted herein, any of the components of any embodiment described herein may be used with any other embodiment. The embodiments described and illustrated are non-limiting.

FIG. **16** illustrates a process **1600** for fabricating a power card (e.g., power card **200**, **500**, **800**) described herein. An N lead frame (e.g., N lead frame **206**) is fabricated (step **1602**). The N lead frame has a body portion (e.g., body portion **232**) and a terminal portion (e.g., terminal portion **226**) extending outward from the body portion. The N lead frame may be fabricated by stamping, etching, casting, or any other method for fabricating lead frames. The N lead frame may be made of a conductive material, such as copper or an alloy of copper.

A P lead frame (e.g., P lead frame **208**) is fabricated (step **1604**). The P lead frame has a body portion (e.g., body portion **230**) and a terminal portion (e.g., terminal portion **224**) extending outward from the body portion. The P lead frame may be fabricated by stamping, etching, casting, or any other method for fabricating lead frames. The P lead frame may be made of a conductive material, such as copper or an alloy of copper.

An O lead frame (e.g., O lead frame **204**, **504**, **604**, **704**, **804**, **1104**, **1404**, **1504**) is fabricated (step **1606**). The O lead frame has a body portion (e.g., body portion **228**) and a terminal portion (e.g., terminal portion **222**) extending outward from the body portion. In some embodiments, the O lead frame has one or more cooling portions (e.g., cooling portion **808**, **1108**, **1408**, **1508**) extending outward from the body portion instead of a terminal portion. The O lead frame may be fabricated by stamping, etching, casting, soldering, molding, or any other method for fabricating lead frames. The O lead frame may be made of a conductive material, such as copper or an alloy of copper.

A first power device (e.g., power device **202**) is coupled to the body portion of the N lead frame and the body portion of the O lead frame (step **1608**). The first power device may have a first side (e.g., first side **480**) coupled to the body portion of the N lead frame. The first power device may have a second side (e.g., second side **482**) coupled to the body portion of the O lead frame.

A second power device (e.g., power device **202**) is coupled to the body portion of the O lead frame and the body portion of the P lead frame (step **1610**). The second power device may have a first side (e.g., first side **480**) coupled to the body portion of the O lead frame. The second power device may have a second side (e.g., second side **482**) coupled to the body portion of the P lead frame.

Solder may be located between the components of the power card, and reflow soldering may be used to connect the respective components of the power card together, as described herein.

The N lead frame, the O lead frame, and the P lead frame may be oriented such that the terminal portion of the O lead frame is at a first end of the power card and the terminal portion of the P lead frame and the terminal portion of the N lead frame are at a second end of the power card.

An insulator may be disposed between the terminal portion of the P lead frame and the terminal portion of the N lead frame. A first signal terminal may be connected to the first power device using solder balls, and a second signal terminal may be connected to the second power device using solder balls.

The resin (e.g., resin **210**) may encase a portion of the power card. The resin may be injection molded to the power card such that all gaps between the components of the power card are occupied with resin. The terminal portion of the O lead frame, portions of the sets of signal terminals, a portion of the terminal portion of the P lead frame, and a portion of the terminal portion of the N lead frame may not be covered in resin, with the remaining components of the power card being encased in resin. The exposed portion of the terminal portion of the P lead frame may be the top surface of the terminal portion. The exposed portion of the terminal portion of the N lead frame may be the bottom surface of the terminal portion.

The cooling portions (e.g., cooling portion **808**, **1108**, **1408**, **1508**) may also be terminal portions of their respective O lead frames, configured to provide an output signal, as described herein.

Exemplary embodiments of the methods/systems have been disclosed in an illustrative style. Accordingly, the terminology employed throughout should be read in a non-limiting manner. Although minor modifications to the teachings herein will occur to those well versed in the art, it shall be understood that what is intended to be circumscribed within the scope of the patent warranted hereon are all such embodiments that reasonably fall within the scope of the advancement to the art hereby contributed, and that that scope shall not be restricted, except in light of the appended claims and their equivalents.

What is claimed is:

1. A power card for use in a vehicle, the power card comprising:
  - an N lead frame having a body portion and a terminal portion, the terminal portion extending outward from the body portion;
  - a P lead frame having a body portion and a terminal portion, the terminal portion extending outward from the body portion;
  - an O lead frame having a body portion and a terminal portion, the terminal portion extending outward from the body portion, the O lead frame being located between the N lead frame and the P lead frame;
  - a first power device being located on a first side of the O lead frame between the body portion of the N lead frame and the body portion of the O lead frame; and
  - a second power device being located on a second side of the O lead frame between the body portion of the O lead frame and the body portion of the P lead frame, the body portion of the O lead frame having one or more channels configured to receive a cooling liquid for cooling the first power device and the second power device.

2. The power card of claim **1**, further comprising a manifold surrounding the body portion of the N lead frame, the body portion of the P lead frame, and the body portion of the O lead frame, the manifold being fluidly coupled to the one or more channels of the body portion of the O lead frame.

3. The power card of claim **2**, wherein the manifold surrounds a lengthwise periphery of the body portion of the N lead frame, the body portion of the P lead frame, and the body portion of the O lead frame.

4. The power card of claim **2**, wherein the manifold further comprises a plurality of channels configured to receive the cooling liquid.

5. The power card of claim **4**, wherein the manifold further comprises an inlet port fluidly coupled to the one or more channels of the manifold and the one or more channels of the body portion of the O lead frame, the inlet port configured to receive the cooling liquid and provide the cooling liquid to the one or more channels of the manifold and the one or more channels of the body portion of the O lead frame, and
  - wherein the manifold further comprises an outlet port fluidly coupled to the one or more channels of the manifold and the one or more channels of the body portion of the O lead frame, the outlet port configured to receive the cooling liquid from the one or more channels of the manifold and the one or more channels of the body portion of the O lead frame and expel the cooling liquid.

6. The power card of claim **5**, further comprising a first lengthwise edge and a second lengthwise edge opposite the first lengthwise edge, the inlet port located on the first lengthwise edge and the outlet port located on the second lengthwise edge.

7. The power card of claim **4**, wherein the plurality of channels of the manifold include a top channel located radially outward of the body portion of the P lead frame, and a bottom channel located radially outward of the body portion of the N lead frame.

8. The power card of claim **7**, further comprising a first heat sink coupled to the body portion of the P lead frame and a second heat sink coupled to the body portion of the N lead frame,
  - wherein the top channel comprises a plurality of channels defined by fins of the first heat sink and the bottom channel comprises a plurality of channels defined by fins of the second heat sink.

9. The power card of claim **1**, wherein the O lead frame comprises a top portion having the one or more channels formed integrally therein, and a bottom portion coupled to the top portion.

10. A power system comprising:
  - a power card having:
    - an O lead frame located between an N lead frame and a P lead frame,
    - a first power device located on a first side of the O lead frame between the N lead frame and the O lead frame, and
    - a second power device located on a second side of the O lead frame between the O lead frame and the P lead frame, the O lead frame having one or more channels configured to receive a cooling liquid for cooling the first power device and the second power device; and
  - a liquid cooler coupled to the one or more channels of the O lead frame and configured to provide the cooling liquid to the one or more channels of the O lead frame.

11. The power system of claim **10**, further comprising a manifold surrounding the N lead frame, the P lead frame, and the O lead frame, the manifold being fluidly coupled to the one or more channels of the body portion of the O lead frame and the liquid cooler.

12. The power system of claim **11**, wherein the manifold surrounds a lengthwise periphery of a body portion of the N lead frame, a body portion of the P lead frame, and a body portion of the O lead frame.

13. The power system of claim **11**, wherein the manifold further comprises a plurality of channels configured to receive the cooling liquid.

14. The power system of claim **13**, wherein the manifold further comprises an inlet port fluidly coupled to the one or more channels of the manifold and the one or more channels of the O lead frame, the inlet port configured to receive the cooling liquid from the liquid cooler and provide the cooling liquid to the one or more channels of the manifold and the one or more channels of the O lead frame, and
  - wherein the manifold further comprises an outlet port fluidly coupled to the one or more channels of the manifold and the one or more channels of the O lead frame, the outlet port configured to receive the cooling liquid from the one or more channels of the manifold and the one or more channels of the O lead frame and expel the cooling liquid to the liquid cooler.

15. The power system of claim **13**, wherein the plurality of channels of the manifold include a top channel located radially outward of the P lead frame, and a bottom channel located radially outward of the N lead frame.

16. The power system of claim **15**, further comprising a first heat sink coupled to the body portion of the P lead frame and a second heat sink coupled to the body portion of the N lead frame,
  - wherein the top channel comprises a plurality of channels defined by fins of the first heat sink and the bottom

channel comprises a plurality of channels defined by fins of the second heat sink.

17. The power system of claim **10**, wherein the O lead frame comprises a top portion having the one or more channels formed integrally therein, and a bottom portion coupled to the top portion.

18. The power system of claim **10**, wherein the liquid cooler is coupled to a vehicle device and configured to provide the cooling liquid to the vehicle device.

19. A lead frame for use in a vehicle power card, the lead frame comprising:

a body portion having a first side coupled to a first power device, a second side coupled to a second power device, and one or more channels configured to receive a cooling liquid for cooling the first power device and the second power device; and

a terminal portion extending outward from the body portion.

20. The lead frame of claim **19**, further comprising a top portion having the one or more channels formed integrally therein, and a bottom portion coupled to the top portion.

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